Research Problem Review 76-11

LEVEL II

AD A076648

TARGET PRESENTATION METHODOLOGY FOR TACTICAL FIELD EVALUATIONS

FORT HOOD FIELD UNIT

U. S. Army

Research Institute for the Behavioral and Social Sciences

October 1976

U. S. ARMY RESEARCH INSTITUTE

FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency under the Jurisdiction of the Deputy Chief of Staff for Personnel

J. E. UHLANER Technical Director	W. C. MAUS COL, GS Commander

NOTICES

~~Army Project Number~~
16 2Q763731A775

TCATA
DAHC 19-75-C-0025

14 ARI-RES PROBLEM-REV-76-11

Research Problem Review 76-11

6

TARGET PRESENTATION METHODOLOGY FOR TACTICAL FIELD EVALUATIONS

10 Jeffery L. Maxey, William H. Ton, William L. Warnick, [redacted] Albert L. Kubala
[redacted]

George M. Gividen, Chief
Fort Hood Field Unit

12 256

Submitted By:
Joseph Zeidner, Director
ORGANIZATIONS AND SYSTEMS
RESEARCH LABORATORY

Approved By:
J. E. Uhlaner
TECHNICAL DIRECTOR

U. S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES
5001 Eisenhower Avenue, Alexandria, Virginia 22333

Office, Deputy Chief of Staff for Personnel
Department of the Army

11 Oct[redacted]76

Research Problem Reviews are special reports to military management. They are usually prepared to meet requests for research results bearing on specific management problems. A limited distribution is made--primarily to the operating agencies directly involved.

FOREWORD

The Fort Hood Field Unit of the Army Research Institute for the Behavioral and Social Sciences (ARI), by assessing the human performance aspects of man/weapons systems evaluations in field situations, provides support to Headquarters, TCATA (TRADOC Combined Arms Test Activity, formerly called MASSTER--Modern Army Selected Systems Test Evaluation & Review). A war using modern weapons systems is likely to be both intense and short; U.S. man/weapons systems must be effective enough, immediately, to offset greater numbers of an enemy. Cost-effective procurement of improved and/or new combat systems requires testing that includes evaluation in operational settings similar to those in which the systems would be used, with troops representative of those who would be using the systems in combat. The doctrine, tactics, and training packages associated with the systems being evaluated must themselves also be tested and refined as necessary.

For the present report, a literature survey identified target-acquisition factors and probable threat tactics and targets. This information then was integrated into a target-presentation methodology which will be used in testing selected visual acquisition capabilities of ground observers.

ARI research in this area is conducted as an in-house effort augmented by contracts with organizations with unique capabilities for human factors research. The present research was done jointly by personnel from the ARI Fort Hood Field Office and the Human Resources Research Organization (HumRRO), under contract DAHC 19-75-C-0025, and is responsive to the special requirements of TCATA and the objectives of RDTE Project 2Q763731A775, "Human Performance in Field Assessment," FY 1976 and 1977 Work Programs.

J. E. UHLANER,
Technical Director

Accession For	
NTIS GRA&I	☑
DDC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or special
A	

TARGET PRESENTATION METHODOLOGY FOR TACTICAL FIELD EVALUATIONS

BRIEF

Requirement:

The research requirement was to develop a standard, general-purpose target presentation methodology that could be employed to evaluate visual target acquisition equipment in future US Army field tests.

This developmental effort was directed toward the accomplishment of the following tasks:

- The identification of the factors which influence the target acquisition process
- The determination of the effects of these factors on the acquisition process in a ground environment.
- The identification of the targets and tactics likely to be encountered in a European battlefield environment.
- The integration of the results of the above tasks into a standard, general-purpose presentation methodology suitable for employment in field test evaluations.

Procedure:

As a first step in this developmental effort, a review of the military and psychological literature was conducted to collect the information pertaining to the (a) factors important in the target acquisition process, and (b) Threat targets and tactics likely to be encountered on the modern battlefield. Following the review of the literature, the information collected on these topics was integrated into a target presentation methodology.

Principal Findings:

- Analysis of the military and psychological research yielded 24 variables (eight target, seven environmental, five task, and four observer variables) which are likely to affect the visual acquisition process for ground-to-ground target situations.

- Threat forces are basically composed of armored and mechanized infantry units with tanks, armored combat vehicles, and self-propelled, tracked air defense weapon systems constituting the primary targets on the modern battlefield.

- Threat forces employ a wide variety of antiarmor weapon systems which are designed to form an interlocking defense system effective over ranges from 0 to 3500 meters. These limits basically define the kill zone of the modern battlefield with respect to Threat antiarmor weapons.

- Threat forces stress the attack and will resort to the defense only as a temporary expedient.

- Threat forces train for and plan to operate on a 24-hour battle-day. *Quick Attacks* may be expected during the day, while *Deliberate Attacks* may be expected during the night.

- Field tests of target acquisition systems should employ the targets and study operational situations that correspond to the Threat targets and situations likely to be encountered on the modern battlefield.

- Frequently in past field research, mistakes have been made with respect to factors known to influence the acquisition process in terms of the manner in which the targets have been defined and deployed in test environments. In order that these mistakes are not repeated in future field research, test planners should properly account for each of the 24 factors known to affect the acquisition process, e.g., through proper target definition, through proper test site selection, and through the employment of good principles of experimental procedure.

Utilization of Findings:

The employment of the results of this developmental effort by test planners and research workers during the planning and design phases of target acquisition field tests will improve the validity of the test data obtained in these tests and minimize the likelihood of erroneous test conclusions.

TARGET PRESENTATION METHODOLOGY FOR TACTICAL FIELD EVALUATIONS

CONTENTS

	Page

Figures Page

CHAPTER 1

INTRODUCTION

Since World War II considerable interest has been shown in the problem of target acquisition, i.e., the detection, identification, and location of a target in sufficient detail to permit the effective employment of weapons.[1] For example, during World War II considerable research was conducted under the auspices of the Armed Forces Vision Committee into the problem areas of ground-to-air and air-to-ground acquisition. More recently, interest in this area has stemmed from several sources: (a) the development of weapon and fire-control systems that can engage targets at ranges far in excess of the ability of the unaided human observer to acquire them, (b) the requirement to conduct tactical operations in jungle and other low-visibility environments, and (c) the expectation that future military operations are likely to take place on a 24-hour basis with a premium being placed on night operations.[2] For these reasons, the problem of target acquisition has been and is a continuing problem for the military establishment of the United States.

As a consequence of the problems created by new weapons technology and requirements to operate in low-visibility environments, considerable attention has been directed to the improvement of the human observer's ability to acquire targets through the development of special sensor

---

[1] *Dictionary of United States Military Terms for Joint Usage.* Department of Defense, JCS Publication 1, August 1968.

[2] D. Jones, M. Freitag, and S. Collyer. *Air-to-Ground Target Acquisition Source Book: A Review of the Literature,* Martin-Marietta Corporation, Orlando, Florida, 1974.

systems. For example, the recent tactical operations conducted in Southeast Asia required the various US military services to perform their missions under conditions of low illumination. This resulted in the requirement to improve their capability to conduct such operations.[3] In turn, this need led to the development of sensors to improve the seeing and target acquisition capabilities of military personnel on the ground and in the air under conditions of reduced illumination.

Generally, the developmental cycle for military equipment includes tests to determine whether the equipment meets specified design and operational requirements. Since target acquisition devices have been developed successively over a period of years, the specific requirements governing their development have varied considerably as a function of parameters defining the particular operational environment and the nature of the enemy and his weapon systems. One consequence of this variation has been that the target acquisition situations employed during testing have varied considerably between studies. This had made it extremely difficult to compare the results of target acquisition studies except in a broad sense.

It is well known from studies conducted in the laboratory and in the field that a large number of factors influence the acquisition of targets by the aided and unaided human eye. This generally makes it next to impossible to study all factors in any given test. However, if a standard, general-purpose target presentation methodology was developed for target acquisition equipment field tests, this would

---

[3] *Night Operations and the Employment of Night Vision Devices (U)*, US Army Combat Development Command, November 1964 (SECRET).

facilitate future research. In particular, it would make the comparison of studies conducted at different test sites at different times under varying environmental conditions a much easier and more profitable task for the researcher evaluating new equipment.

It was the purpose of the present research to develop such a target presentation methodology for testing acquisition systems employed in a ground combat role. As a first step in this direction, a review of the military and psychological literature was conducted to identify those factors likely to be important in developing a standard, general-purpose target presentation methodology. In particular, this review was oriented toward the identification of independent variables likely to affect target acquisition in field environments and the determination of the kinds of targets and tactics likely to be encountered on the battlefields of tomorrow.

Next, based on the results of this review, the target presentation methodology was developed. The development of this methodology was accomplished through a logical synthesis of the identified target acquisition factors and the targets and tactics identified as likely to be encountered in future operational military environments. This methodology constitutes the product of the research and is described in full in this report along with the research base from which it was developed.

Military Problem

In the past, military evaluations of target acquisition devices have often been conducted under unrealistic field conditions. In some cases this has been done deliberately, while in others it has been done because of the lack of an adequate methodology for developing tactically valid target acquisition situations. For example, in some cases field evaluations of target acquisition devices have been deliberately conducted under optimal conditions in order to determine the absolute capabilities of these devices. While such tests are naturally favored by the developer, the test results from these evaluations tend to present an exaggerated picture of the capabilities of the evaluated devices. As a consequence, the extrapolation of such results by military planners to operational situations can conceivably lead to the development of inappropriate doctrine for the deployment of the target acquisition devices.

In other cases, field evaluations of acquisition devices have been conducted within the context of situations that have not necessarily realistically simulated potential enemy targets and/or their deployment. Examples of tactically invalid targets are numerous: a single tank target advancing down a long straight road toward an observer, unrealistically colored aircraft (e.g., aircraft painted luminescent orange), and single personnel targets walking upright across open areas without attempting to use natural cover. Extrapolation of the results from these studies could also lead military planners to make inappropriate decisions with respect to the deployment of the evaluated devices.

Finally, in some field tests of acquisition devices it has been the case that highly critical parameters describing the exact physical conditions of the evaluation have not been measured and specified in technical reports of these investigations. Examples of such critical parameters are the level of ambient illumination, the meteorological visibility, and target/background contrast ratio. The failure to measure and report these critical parameters has made it virtually impossible to precisely compare the results obtained from one data collection session to another. More importantly, it has made between-test and between-device comparisons relatively difficult, if not impossible. Further, it is likely that certain operational conditions which may contribute to the obtained results of a military field test have not been assessed and specified in test reports. Examples of such conditions would be: (a) targets which appear at regular and/or too frequent intervals, (b) unrealistic warning information provided to observers specifying the target type, as well as the time and direction of approach by the target, and (c) the representativeness of the test observers to likely acquisition device users. The failure to specify these kinds of information, in addition to making test comparisons relatively impossible, can also lead military planners to make inappropriate decisions with respect to evaluated target acquisition equipment.

Target acquisition is an extremely important aspect of military operations. Current military doctrine with respect to the modern battlefield clearly states that what can be seen can be hit, and what can be hit can be killed.[4] Thus, the side which acquires targets first has an obvious tactical advantage. Therefore, for the purposes of planning, for both the purchase and deployment of acquisition devices, it is imperative that the real tactical capabilities of target acquisition devices be known. In particular, a system for ensuring that tactically valid

[4]TRADOC Bulletin 8. *Modern Weapons on the Modern Battlefield*, US Army Training and Doctrine Command, Fort Monroe, Virginia.

target situations are employed during military tests of target acquisition equipment is needed. With such a system, it will be possible to obtain realistic data that can be used by military planners to identify target acquisition systems that will provide the US Army with the capability to see targets first on the modern battlefield.

Research Problem and Approach

The research problem in the present effort was to *develop a standard, general-purpose target presentation methodology that could be employed to evaluate visual target acquisition equipment in future US Army field tests*. In addition, it was necessary to identify those target acquisition factors that should be measured or controlled during field testing in order to provide a basis for between-field test comparisons. Further, by identifying these factors, a basis could be established for determining the extent actual field tests conditions approximate those called for in a given target presentation design plan.

The research problem resolved into four basic component problems: (1) the identification of the factors which influence the target acquisition process, (2) the determination of the effects of these factors on the acquisition process in a ground environment, (3) the identification of the targets and tactics likely to be encountered under various environmental/geographical conditions in a central European battlefield environment, and (4) the integration of the above information into a standard, general-purpose presentation methodology suitable for employment in field test evaluations. In addition, it was determined that guidelines for the measurement and control of relevant acquisition factors during field testing should be developed.

As a first step in the present research, a review of the military and psychological literature was conducted to collect the information pertaining to the (a) factors important in the target acquisition process, and (b) threat targets and tactics likely to be encountered on the modern battlefield. Following the review of the literature, the information collected on these topics was integrated into a target presentation methdology. This methodology addresses the following subject matter areas:

a. the factors that should be evaluated and/or controlled during a target acquisition field study,

b. the likely effects of each of the above factors on the target acquisition process,

c. the threat targets which should be realistically simulated during a target acquisition field study,

d. the appropriate situations for evaluating target acquisition systems deployed in either offensive or defensive combat roles.

This report then presents the above described target presentation methodology and, in addition, the results of the review of the military and psychological literature found to be relevant to the research problem.

CHAPTER 2

LITERATURE REVIEW

Factors Involved in the Ground-to-Ground Target Acquisition Process

The major objective of the current research was to identify those factors likely to be important in developing a standard, general-purpose target presentation methodology for use in evaluations of target acquisition systems in a ground combat role. To this end, a review of the literature on visual target acquisition was conducted to identify the behavioral, environmental, and situational variables which affect the ability of human observers to perform visual acquisition tasks in field situations. Some 300 reports, books and journal articles were acquired and examined during the course of the literature search. The literature in this area was found not only to be extensive, but also quite diverse in content. Therefore, it was judged appropriate in the initial stages of the review to employ some criteria for limiting the literature surveyed to material that was directly relevant to the specification of valid targets for evaluations of ground-based target acquisition systems. As a consequence, the following criteria were employed to limit the scope of the literature surveyed:

1. Only ground-to-ground target acquisition was considered. In view of the fact that the results of the review were to serve as input for specifying valid target situations for evaluations of acquisition systems deployed in a ground combat role, it was judged appropriate to limit the overall scope of the review primarily to studies conducted in ground-to-ground acquisition situations. Other acquisition situations, e.g., air-to-ground and ground-to-air, were considered only when it was not possible to locate research conducted in a ground-to-ground acquisition situation that involved variables judged to be logically relevant to the acquisition process in this mode.

2. Only real-time target acquisition studies were considered for review. Studies involving photographic or recorded imagery were generally not included. Also, computer simulations were not included.

3. Studies involving the use of optical and electro-optical systems as aids to target acquisition were considered in addition to studies involving unaided (naked eye) target acquisition. Practically speaking, this restriction limited the studies considered for review to those which directly involved the processing by the human visual system of light reflected or emitted by a target in an acquisition situation. As a consequence, studies involving target acquisition via systems such as radar or sonar were excluded from the review.

4. While classified material was reviewed, it was not included in this review. There were two basic reasons for this restriction. First, it was desired that this review be generally available to the scientific community as a whole. Second, much of what is classified in this area was not sufficiently relevant to the aims of the review. As such, this material's inclusion would have added little real substance.

5. The emphasis in this review was on the data provided by studies conducted in applied field settings. Laboratory research was generally considered only when field studies were few or were not available for certain acquisition variables.

6. For the purposes of this review, target acquisition was viewed as a generic term that covered not only the detection process, but also the processes of recognition and identification. As such, the term *target acquisition* was employed as a neutral term whose meaning was largely dependent on the problem of targeting[1] with which the reviewed studies were concerned. For example, if the target problem of a study was solved when a target was detected, then acquisition was said to have taken place.

After application of these criteria for selection of literature, some 100 of the documents examined were deemed of sufficient relevance to be appropriate for review in depth. Eighty-four of these were finally chosen for inclusion in the review.

---

[1] Targeting refers to the process completed by an observer in a situation minimally defined by the presence of some object (the target) presented in some content (the background) and the requirement to make and report a judgment about the target's presence with respect to some predefined rule (criteria).

It seems reasonable to assume that a common set of factors determine the perception of objects in the visual world.[2] Of course, under certain conditions, it is to be expected that the contribution of any factor or group of factors may be negligible. However, to ensure adequate experimental control and to facilitate the replication of experimental research, it is important to explicitly account for each factor important to the perception process. This is particularly true whenever target acquisition research is conducted in outdoor settings.

Previous research by the present author in this problem area[3,4] was guided by a theoretical orientation described by Woodworth.[5] He suggested that an organism's responses (measured by dependent variables, e.g., time to detection, percent detections, accuracy of identification) are a function of both stimulus (external) and organismic (internal) events. As this orientation proved to be useful for organizing relevant target acquisition literature in this prior research, it was employed during the current review of this problem area.

---

[2]T. Nichols and T. Powers. *Moonlight and Night Visibility*, HumRRO Research Memorandum, Human Resources Research Organization, Alexandria, Virginia, January 1964.

[3]J. Caviness, J. Maxey, and J. McPherson. *Target Detection and Range Estimation*, HumRRO Technical Report 72-34, Human Resources Research Organization, Alexandria, Virginia, November 1972.

[4]J. Caviness and J. Maxey. *Detection of Human Targets*, HumRRO Technical Report 74-4, Human Resources Research Organization, Alexandria, Virginia, February 1974.

[5]R. Woodworth and H. Schlosberg. *Experimental Psychology*, New York: Holt and Company, 1954.

The stimulus or external events considered for their effect on the acquisition process fell in three broad categories: object (target) characteristics, environmental (background) characteristics, and task (situational) characteristics. In general, these categories of independent variables were defined in the following ways. Object characteristics were defined as those parameters which described the target to be acquired in a given situation. Environmental characteristics were defined as those parameters which described the physical situation in which the target appeared. Finally, task characteristics were defined as those parameters which delineated the rules and procedures under which the observer operated during the acquisition task.

The organismic or internal events considered for their effect on the acquisition process were those observer characteristics which could logically affect the observer's capacity to perform the acquisition task. In general, it was expected that relevant individual differences reflect distributions of preestablished skills or abilities that differentially assist or hinder the performance of the acquisition task.

Thus, for the purpose of this section of the report, two general classes of variables (stimulus and observer) were considered for their effects on the performance of the acquisition task under field conditions. In particular, it was assumed that criterion measures of acquisition (measures of correctness, timeliness, and accuracy) were dependent upon object characteristics, environmental characteristics, task characteristics, and observer characteristics. However, it should be recognized that in "real world" situations it is generally the case that interdependencies of one degree or another exist among these classes of characteristics. For example, target contrast is always measured with respect to a particular target and a particular background. Variations in shape are generally correlated with variations in size. Changes in both target size and target range significantly affect the size of the visual angle seen by an observer. The range at which a target can be expected to be available for detection often limits the amount of visual space that must be searched during the acquisition process. Thus, at any one time it may be expected that a number of factors will play a part in the acquisition process. Further, due to the existence of these interdependencies it can be expected that "pure" examples of these characteristics never exist in the natural world. Therefore, while this review will address the effects of selected stimulus and observer characteristics as if they existed in pure independent states under natural viewing conditions, it should always be remembered that this does not completely reflect the true situation.

Stimulus Variables

The majority of the research conducted on the problem of target acquisition has focused on the effects of various stimulus variables. Caviness and Maxey[6] point to three reasons for this state of affairs. First, perceptual questions have historically been the domain of experimental psychology. Second, external variables are usually more available and easier to manipulate than organismic variables. Third, manipulation of external variables is often the most logical course for

[6] J. Caviness and J. Maxey, *op. cit.*

the experimenter to take in determining the basis of the human perceptual response. This disposition reflects the experimentalist's assumption that humans are more alike in the way they behave than they are different. For these reasons then, target acquisition research has studied the detection of objects in terms of their attributes and the interactions of these attributes with certain environmental and task characteristics.

Target Characteristics

The objects which have served as targets in acquisition studies have varied in many different ways: size, shape, color contrast with the background, brightness contrast, distance from the observer, duration of exposure, and presence of motion. It is the purpose of this section of the review to discuss the effects of these characteristics on target acquisition.

Size. Research on the effect of target size on acquisition performance has been conducted in the laboratory and in the field. In the laboratory size is manipulated by varying the visual angle subtended by a particular target object, usually a uniform circular disk. This manipulation is accomplished by either varying the distance at which a standard sized target is viewed or by varying the linear size and/or area of a target with viewing distance held constant.

In field research, target size is usually varied in one of two ways: (a) by employing different types of targets (e.g., men, tanks, jeeps) that vary in their physical dimensions with target-to-observer range held constant, or (b) by varying the number or percent of a given type of target, with viewing distance held constant. Target size (in terms of visual angle) can also be varied by changing the viewing distance to a given target. However, in a field situation, changes in range are normally highly correlated with a number of other factors which influence the acquisition process, such as brightness contrast and color contrast. Therefore, in order to assess the effects of size alone, the two previously described means of manipulating size are preferable.

For both laboratory and field studies the common finding is that, other things being equal, as target size is increased from small values to large values, the probability of detection increases up to and including unity. Blackwell and Taylor's survey of laboratory studies of visual detection[7] covers a representative sample of laboratory results in this area. In these studies circular disks of varying area were viewed against backgrounds of uniform luminances. Observers were allowed to view the target objects without any restrictions on the amount of time they spent in observation. Viewing times ranged from 10 to 30 seconds. Further, in these studies the targets were in the most favorable viewing position as selected by the observer. The general finding was that as the target area increased, the 50 percent contrast threshold decreased, i.e., acquisition performance improved.

Relatively few field studies of ground-to-ground acquisition have manipulated the size variable. Richardson (in an analysis of data

---

[7]H. Blackwell and J. Taylor. *Survey of Laboratory Studies of Visual Detection,* paper presented at the NATO Seminar on Detection, Recognition, and Identification of Line-of-Sight Targets, The Hague, Netherlands, 25-29 August 1969.

collected during a Combat Developments Command Experimentation Center [CDCEC] study) reported that the size of tactical ground targets was significantly related to their detectability.[8] Four classes of targets were evaluated: personnel targets, small equipment targets (jeep, towed field gun), medium equipment targets (2.5-ton truck, armored personnel carrier), and large equipment targets (tank, five-ton truck). The targets were located at 53 presurveyed locations within three range bands centering on 1000, 3000, and 5000 meters. Further, depending on the experimental condition, the targets were either stationary or moving with movement being either local (in place) or slow in a lateral direction. In order to control for differences in target range, the apparent size (i.e., the visual angle) of each target was determined. These targets were observed during daylight hours by military observers. In general, the detectability of the targets increased as the size of the targets increased, e.g., percent detections increased as target size increased.

Caviness and Maxey[9] also conducted a study investigating the effect of target size on the acquisition performance of military observers. In this study all observations were completed without visual aids. Under conditions of normal daylight illumination, observers acquired single, double, triple-in-line, and triple-in-file personnel targets walking toward their positions across a grassy field on the Fort Benning Military Reservation in Georgia. They found no significant differences in the detection range or in the time to detection for the varying target sizes investigated.

---

[8] F. Richardson. *Target Acquisition Performance by Ground Observers - A Physical Interpretation*, Technical Report, Army Combat Developments Command, Fort Ord, California, July 1968.

[9] J. Caviness and J. Maxey, *op. cit.*

Taken together, these two studies suggest that for physical target size to matter in ground-to-ground field studies conducted under full daylight illumination, the differences in the relative target size must be quite large. Otherwise, acquisition performance will be little affected by the size variable.

Size as a variable has also been investigated under low illumination conditions. In a study conducted at the Japanese Infantry School during the mid-1930s,[10] infantry observers acquired single soldier, patrol size, and unit size targets under varying conditions of low illumination without visual aids. As target size increased, the range at detection also increased. Similar results were found by Taylor[11] in a study conducted under both starlight and full-moon illumination conditions. In this study, targets were standing, kneeling, or prone infantrymen. For both conditions of low illumination, standing targets were easier to detect than kneeling targets, while kneeling targets were easier to detect than prone targets. Again, all observation was conducted without visual aids. In a study conducted at Fort Knox, Kentucky, during 1959[12] similar results were obtained for small (e.g., two-man tents), medium (e.g., jeep), and large (e.g., 2.5-ton truck equipment targets. As target size increased the detection range for targets increased. All testing in this study was

---

[10] "Principles of Night Combat," *Japanese Night Combat, Part 1*. Headquarters, US Army Forces, Far East, Eighth US Army Military Section, Japanese Research Division, undated.

[11] J. Taylor. *Moonlight I: Identification of Stationary Human Targets*, HumRRO Research Memorandum 21, Human Resources Research Organization, Alexandria, Virginia, December 1960.

[12] H. Martinek, R. Tanck, and J. Mellinger. *Field Evaluation of ANST-Armoured Patrol*, Research Memorandum 59-12, Personnel Research Branch, Adjutant General's Office, November 1959.

conducted under moonless and cloudless conditions. Subjects were dark adapted prior to making their observations.

Finally, Sternberg and Banks[13] (during an investigation of search effectiveness with passive night vision devices) had observers detect both personnel and vehicular targets under low illumination conditions. Personnel targets were placed at near (100-300 meters) and mid (350-800 meters) distances, while vehicular targets were placed at mid and far (800-1200 meters) distances from the observer's position. This arrangement was employed to conserve experimental resources, since it had been found in earlier work that personnel targets had a low probability of detection at the far distances, while vehicular targets had a high probability of detection at the near distances. In general, they found for all conditions of low illumination studied that vehicular targets were detected at a higher rate than personnel targets. However, due to the above mentioned target placement arrangement, the advantage of size differences in the targets for detection performance is only suggested.

These studies thus indicate that size can be a factor in acquisition of targets by human observers under conditions of full and reduced illumination for both aided and unaided observation. However, the evidence strongly suggests that differences in relative target size must be large for this variable to become influential. For small differences in relative size, other factors are likely to be more important in the acquisition process.

---

[13] J. Sternberg and J. Banks. *Search Effectiveness with Passive Night Vision Devices*, Technical Research Report 1163, Behavior and Systems Research Laboratory, Arlington, Virginia, June 1970.

Shape. The shape of a target is an obvious physical characteristic, and as such, it is intuitively appealing to suppose that this characteristic is an important factor in the target acquisition process. In natural settings potential target objects varying in shape appear in the context of other non-target objects which also tend to vary in shape. Thus, the effect of shape variations on target acquisition performance is likely to be influenced by the type and variety of background shapes present during the completion of the acquisition task. In addition, due to the presence of camouflage and the expected mobility of many potential targets in field situations (e.g., tanks, jeeps, scout vehicles, etc.), it may be expected that target shape will show significant variations during the course of an engagement for particular target objects. Thus, it may be expected that the effect of shape variations on target acquisition performance in field settings will depend not only on obvious differences in target shapes, but also on the interaction of these differences with background shape differences and the change in both target and background shape differences over time.

Research on the effect of target shape on detection performance has been conducted primarily in the laboratory. No ground-to-ground acquisition studies were found that specifically addressed the question of the effect of shape on acquisition performance. Shape is a characteristic that is very difficult to specify once one goes beyond geometrical forms. In particular, most natural objects or man-made objects likely to be available for detection in a field situation have complex shapes composed of many intersecting angles and contours. Further, in manipulating this variable, it is always necessary to ensure that target area for different shapes is held constant. Otherwise, any differences found between differently shaped targets could also be attributed to differences in target area. For these reasons, experimental psychologists have generally preferred to conduct research on the effects of shape on detection performance in laboratory situations.

One of the earliest studies concerned with the role of shape in the process of detection was conducted by Helson and Fehrer.[14] The purpose of their study was to determine the thresholds for (a) just seeing light, (b) perceiving just-noticeable form, and (c) perceiving definite form. Six different targets (isosceles triangle, rectangle, circle, semicircle, inverted "v" figure, and square) of equal area were studied. For all forms it was found that the threshold for the detection of light was lower than the threshold for just-noticeable form. In general, it was found that the threshold for just-noticeable form was twice that of the threshold for the detection of light. Further, it was found that the threshold for perceiving definite form varied as a function of the form's shape. That is, it was found that some forms required less light relative to the other forms to be correctly recognized. For example, the rectangular target required less light for correct recognition when compared to the other form investigated.

More recently, Fox[15] investigated the effect of form differences on perception. In this investigation, six different target shapes (circle,

---

[14] H. Helson and E. Fehrer. "The Role of Form in Perception," *American Journal of Psychology*, 1932, 44, 79-102.

[15] W. Fox. *Visual Discrimination as a Function of Stimulus Size, Shape, and Edge Gradient*, WADC Technical Note 57-132, Wright Air Development Center, Wright-Patterson AFB, Ohio, August 1957.

irregular figure, square, triangle, cross, and star) of equal area were studied. Since target area was held constant in this study, there was some variation in the perimeter-to-area ratio, but this was judged to be minimal. In addition, targets varied in size from small (average visual angle = 12.3 minutes) to medium (average visual angle = 65.6 minutes) to large (average visual angle = 123.7 minutes). All targets were presented against a homogeneous well-lighted background.

Data analysis revealed that observer detection performance was affected by variations in target shape for only the medium and large sized targets. In particular, detection thresholds were greater for the cross and irregular shaped targets than for the circular, square, triangular, and star shaped targets for both the medium and large size conditions. For the small size condition, detection thresholds were not found to vary significantly among the target figures.

Kristofferson[16] has also investigated the effect of variations in target shape on target acquisition performance. In this research the detectability of circular and non-circular (rectangular, spoked, and geometric shaped forms) targets, equated for area, was investigated. In general, his research found that non-circular targets had higher detection thresholds than circular targets.

These studies seem to suggest that target shape should be a factor in the process of target acquisition. Different shapes do appear to differ

---

[16] A. Kristofferson. *Visual Detection as Influenced by Target Form*, paper presented at Target Acquisition Symposium, Naval Training Device Center, Orlando, Florida, November 1972.

in their relative detectability. However, in natural environments shapes do not occur in isolation. They always occur in the context of other shapes. As a consequence, the importance of shape for target acquisition in the field is likely to be in terms of the discriminability of target shape from background shape.

For example, Smith[17] investigated the effect of variations in target-background shape similarity on target acquisition performance. In this study four target shapes were investigated: triangle, square, pentagon, and hexagon. These shapes were presented against a background composed of circular shapes of equal contrast and area. In all cases, target and background shapes were presented well above threshold detection levels. It was found that as the similarity between the target and background shapes increased, the time required to locate the target increased, i.e., the ease of acquisition decreased with increased similarity of target and background shape.

These results clearly suggest that target shape is likely to be a factor in the acquisition of targets in a field environment, particularly when the target appears in the context of non-target objects of similar shape. However, this conclusion is based on the results of laboratory work. As such, it remains to be verified by research conducted under field conditions employing target and background shapes characteristic of a combat environment.

---

[17] S. Smith. *Time Required for Target Detection in Complex Abstract Visual Displays*, Memorandum 2900-235-R, University of Michigan, Ann Arbor, April 1961.

Color. The human eye is differentially sensitive to different levels of ambient illumination. This is due to the existence of two different kinds of receptor organs located in the retina of the eye -- rods and cones. The central area of the retina is composed largely of cones with a very few rods, while in the peripheral areas, the reverse is true. The cone receptors mediate photopic or "daylight" vision, while the rods mediate scotopic or "night" vision. One property of photopic vision is that, depending upon the wavelengths of light which reach the cone receptors, objects appear to have hue or color. As the intensity of the ambient illumination which reaches the eye is lowered, colored objects first lose their brillance and then become colorless.[18] A similar result occurs when the intensity of the illumination reaching the eye is increased to relatively high levels.

Thus, color is a property of objects only under conditions of photopic or daylight illumination. Within the rather wide limits of the electromagnetic energy spectrum, only a very small part of the spectrum affects the receptors of the eye (from about 380 to 760 nanometers).[19] The color manifested by objects viewed under photopic illumination conditions depends on the wavelengths of light reflected from the object. For example, objects which reflect wavelengths from the upper end of the spectrum (from 610 to 760 nanometers) will appear red, while objects which

---

[18] F. Geldard. *The Human Senses*, New York: John Wiley, 1952.

[19] K. von Fieandt. *The World of Perception*, Homewood, Illinois: Dorsey Press, 1966.

reflect wavelengths from the lower end of the spectrum (from 380 to 420 nanometers) will appear violet. In between these ranges, the colors of orange, yellow, green, and blue are produced by the appropriate wavelengths.

In military ground combat situations, the number of colors likely to be observed is limited compared to that experienced in non-military environments. This is because military vehicles and equipment are generally painted some shade of dark green or olive drab or painted in a camouflaged pattern composed of various shades of green, brown, tan or black. Further, personnel usually are dressed in olive drab colored clothing or in clothing covered in a camouflaged pattern composed of greens, browns; tans and black. As a consequence, it may be expected that for military targets, color will be of small importance in the acquisition process. However, this will be true only insofar as the colors of military targets do not sharply differ from that of the environment in which they appear.

Field research supports this conjecture. In a study conducted by the US Army Infantry Board at Fort Benning,[20] it was found that 100 percent of the observers could locate a target wearing a white T-shirt in an area of trees and shrubs at 1400 meters. Conversely, only 10 percent of the observers could locate a target wearing the OG 107 field uniform at 190 meters. Similar results were obtained by Mattimore and Wollanston in a mid-latitude mixed forest (hardwood, white pine, and hemlock

---

[20] *User Review of Individual Camouflage*. Project No. 2989, US Army Infantry Board, Fort Benning, Georgia, March 1963.

trees).[21] In this study, a target wearing a white shirt was seen at an average range of 124 feet [38 meters],[22] while a target wearing an OG 107 field jacket was seen at an average range of only 86 feet [26 meters].

Caviness and Maxey[23] conducted a study at Fort Benning which investigated the effect of target color contrast on target acquisition. The targets in this study wore either an olive drab uniform, a forest green uniform, or a black pajama-type uniform. Two target backgrounds (each correlated with a different avenue of approach) were evaluated in this study. Analysis of their data revealed that there was an interaction between the type of background (avenue of approach) evaluated and target uniform color. For one background, time to detection was least for the black uniform, greatest for the olive drab uniform, and an intermediate value for the forest green uniform. For the other background, the detection time was least for the black uniform, and greater and about equal for the olive drab and forest green uniforms. The results indicated that by changing the background against which a colored target was observed, the relative detectability of the colored target could be altered, as was the case for the forest green targets.

---

[21] R. Anstey. *Visibility Measurement in Forested Areas*, Special Report S-4, Earth Sciences Division, US Army Natick Laboratories, Natick, Massachusetts, November 1964.

[22] For the convenience of the reader, measurements that were made in a non-metric system of measurement were converted to the metric system for purposes of comparison. These conversions were rounded to the nearest meter and are put in brackets adjacent to the non-metric measurement.

[23] J. Caviness and J. Maxey, *op. cit.*

Finally, Skinner and Jenkins[24] have found that the effectiveness of camouflage uniforms decreases with increasing color contrast, independent of brightness contrast. This conclusion was based on an analysis of data collected during an investigation of the camouflage effectiveness of six uniforms which was conducted in a light eucalyptus forest.[25] In this study, military observers searched for six headless pop-up silhouette targets located at target-to-observer ranges of up to 50 meters. The targets were dressed in one of six different uniforms (five disruptively-patterned uniforms and a set of "jungle greens"). Uniform effectiveness was defined in terms of the percentage of targets that remained undetected during the study. In addition, using a telephotometer, measurements of the average color of the background and the uniforms was obtained. Finally, the average length and width of a typical pattern element from each uniform were determined (for the solid uniform, the averages were arbitrarily designated zero). Collectively, these data defined four shape factors (length, width, $\sqrt{l \times w}$, and l/w; two color-brightness contrast factors; and five color-contrast factors. Analysis of these data revealed that a combination of pattern length and color contrast had the highest correlation with camouflage effectiveness. Thus, it was concluded that color contrast, independent of brightness contrast, was a significant factor in the detection of camouflage uniforms.

---

[24] D. Skinner and S. Jenkins. *A Rationale for the Design of a Camouflage Uniform*, MRL Report 598, Materials Research Laboratories, Maribyrnong, Australia, 1974 (RESTRICTED).

[25] G. Smith, D. Skinner, and S. Jenkins. *A Preliminary Comparison of the Detectability of Certain Camouflage Uniforms*, DSL Report 593, Defence Standards Laboratories, Maribyrnong, Australia, 1973 (RESTRICTED).

Thus, it seems clear for target acquisition conducted in field environments, that it is not so much the object color that is critical for detection as it is the contrast of this color with the background in which it appears. Therefore, color contrast, not color, is the important variable for the acquisition process for colored objects. Further, these studies suggest, for military targets which are typically green or brown hued, that these targets will be difficult to detect in field situations characterized by greens or browns. Finally, it can be expected that targets with high color contrast will be detected sooner and further away than targets with low color contrast.

Brightness contrast. In field situations targets always appear in the context of a background. Both targets and their backgrounds may be characterized by the amount of light they reflect toward an observer, i.e., they may be characterized by their respective brightnesses. Brightness contrast is a way of specifying the relative brightness of a target with respect to its background. It is usually defined as the ratio of the difference between measured target and background brightness to the measured background brightness, i.e.,

$$Contrast = \frac{B_t - B_b}{B_b}$$

where B_t is the measured brightness of the target and B_b is the measured brightness of the background. Brightness contrast is said to be positive when the target is brighter than the background, negative when the target is darker than the background, and zero when the target and background are of the same brightness.

In general, for field studies of acquisition the inherent brightness contrast of a target (contrast measured at or near the target) is of less significance than the apparent brightness contrast.[26] Apparent contrast is the brightness contrast of a target relative to its background measured at the observer's eye. It is dependent upon several factors: the inherent brightness contrast, the target-to-observer range, the characteristics of the atmosphere mediating the light transmitted to the eye, and the transfer characteristics of any visual aids employed during observation. In general, apparent brightness contrast is usually somewhat less than inherent contrast. The reason for this is that the above mentioned factors tend to attenuate the inherent target contrast in field situations.

That brightness contrast is important in field studies of target acquisition is borne out by several research efforts conducted under conditions of both high and low ambient illumination. Dobbins, Chu, and Kindick[27] found (in a study of the detectability of camouflaged targets in a Panamanian semideciduous tropical forest) that the brightness contrast of the OG 107 field uniform became a relatively more important cue to detection as target distance was increased. Guttman and Webster found that the visibility of a 30-foot (nine meter) high antennae mast

---

[26] D. Jones, M. Freitag, and S. Collyer. *Air-to-Ground Target Acquisition Source Book: A Review of the Literature*, Martin-Marietta Corporation, Orlando, Florida, 1974.

[27] D. Dobbins, R. Chu, and C. Kindick. *Jungle Vision III: Seasonal Variations in Personnel Detectability in a Semideciduous Tropical Forest*, Research Report No. 8, US Army Tropic Test Center, Panama Canal Zone, January 1967.

was greater against a mountain (high contrast situation) background than against a grass background (low contrast situation).[28] In an analysis of target acquisition performance for ground observers using binoculars, Richardson[29] found that apparent target background contrast significantly affected acquisition performance. Targets in this study were military vehicles and personnel. Gee and Humphreys[30] studied the detectability of colored uniforms as a function of their lightness or darkness. They found the detectability of uniforms that were either lighter or darker than the background was higher than the detectability of uniforms which were about the same lightness or darkness as the background. Finally, Dubuisson and Kindick[31] studied the detectability of moving personnel targets dressed in two differently-colored low-contrast uniforms (green field uniform and black pajama-type uniform) in a jungle environment. They found that the detectability of these uniforms was essentially the same for both the wet and dry seasons in this environment. All of the above studies were conducted under conditions of daylight illumination.

---

[28] H. Guttman and R. Webster. "Determining the Detectability Range of Camouflaged Targets," *Human Factors*, 1972, 14, 217-225.

[29] F. Richardson, *op. cit.*

[30] D. Gee and A. Humphreys. *User Review of Camouflage for the Individual Soldier in the Field*, US Army Engineer Research and Development Laboratories, October 1965.

[31] A. Dubuisson and D. Kindick. *Jungle Vision VIII: Visual Detection of Moving Targets in a Semitropic Forest*, Interim Report, US Army Tropic Test Center, Panama Canal Zone, October 1971.

Similar results have been found for brightness contrast under conditions of low ambient illumination. In a study conducted by the Japanese Infantry School,[32] it was found that targets silhouetted against the sky were always more detectable than those silhouetted against a dark background. This was true for both starlight and various levels of moonlight illumination. Observers in this study used no visual aids. Sternberg and Banks[33] found a similar result in a study designed to evaluate several night vision aids. Targets in this study were placed in low contrast (in front of a tree line) and in high contrast (in an open grass area) settings. It was found that high contrast targets were more detectable than low contrast targets.

Finally, van Meeteren and Zonneveld[34] (in a laboratory simulation of a night vision field problem) studied the effect of variations in target brightness contrast on target acquisition performance. In this study observers acquired targets under conditions of unaided and aided visual observation. Prior to the experiment a landscape mock-up was built with two roads which intersected in the middle of the mock-up. Scale models of tank-sized targets, truck-sized targets, and small personnel and vehicular-sized targets were separately placed at the intersection of the road and photographed. In half of the photographs the road was composed of light colored sand, while in the other half of the photographs, the road was composed of dark colored sand. For targets appearing against the light

---

[32] "Principles of Night Combat," *op. cit.*

[33] J. Sternberg and J. Banks, *op. cit.*

[34] A. van Meeteren and F. Zonneveld. *Object Recognition in Aided and Unaided Night Vision*, Report IZF 1971-7, Institute for Perception RVO/TNO, Sonesterberg, The Netherlands, 1971.

colored road intersection, target contrast was high, while for targets appearing against the dark colored intersection, target contrast was low. From these photographs, slides were prepared for presentation to the observers during the experiment.

During the experiment these slides were randomly presented to observers on a translucent screen such that the apparent viewing distance was 300 meters. The observers viewed the slides either with the naked eye or with the aid of a small Starlight Scope. The scene luminance for each slide was controlled through neutral density filters placed on the slide projector lens. For both aided and unaided vision, ambient illumination (luminance level) and target contrast interacted. At low levels of night illumination, recognition of targets appearing against the light background was superior to recognition of targets appearing against the dark background. However, under conditions of higher illumination, recognition for targets appearing against a dark background was superior to recognition for targets appearing against a light background. Van Meeteren and Zonneveld suggested that this result may have occurred because at higher illuminations, contrast relative to other factors, e.g., internal detail, became less important in the acquisition process.

Taken together, these studies indicate that target brightness contrast is an important factor in target acquisition under conditions of both daylight and night illumination. This appears to be true for both aided and unaided observation. Further, these studies indicate a direct relationship between contrast and acquisition, i.e., increases in contrast are associated with increases in detectability. However, as the van Meeteren and Zonneveld study suggests, as other variables increase in significance, it can be expected that the contrast-detectability relationship may change.

<u>Target range</u>. Target-to-observer range (distance) is one of the most well-studied variables in the target acquisition literature. In general, the finding has been: as target range is increased (with target size held constant), acquisition performance declines under both low and high levels of ambient illumination.

Dobbins and his associates at the US Army Tropic Test Center in the Panama Canal Zone have conducted a number of studies[35,36,37,38,39,40,41,42] which have systematically investigated the effect of target range on

---

[35]D. Dobbins and M. Gast. *Jungle Vision I: Effects of Distance, Horizontal Placement, and Site on Personnel Detection in a Semideciduous Tropical Forest*, US Army Tropic Test Center, Panama Canal Zone, April 1964.

[36]D. Dobbins and M. Gast. *Jungle Vision II: Effects of Distance, Horizontal Placement and Site on Personnel Detection in an Evergreen Rain Forest*, US Army Tropic Test Center, Panama Canal Zone, November 1964.

[37]D. Dobbins, M. Gast, and C. Kindick. *Jungle Vision III: Effects of Seasonal Variation on Personnel Detection in an Evergreen Rainforest*, Research Report No. 3, US Army Tropic Test Center, Panama Canal Zone, May 1965.

[38]D. Dobbins, M. Gast, and C. Kindick. *Jungle Vision IV: An Exploratory Study on the Use of Yellow Lenses to Aid Personnel Detection in an Evergreen Rainforest*, Research Report No. 4, US Army Tropic Test Center, Panama Canal Zone, July 1965.

[39]D. Dobbins and C. Kindick. *Jungle Vision V: Evaluation of Three Types of Lenses as Aids to Personnel Detection in a Semideciduous Tropical Forest*, Research Report No. 5, US Army Tropic Test Center, Panama Canal Zone, December 1965.

[40]D. Dobbins and C. Kindick. *Jungle Vision VI: A Comparison Between the Detectability of Human Targets and Standard Visibility Objects in an Evergreen Rainforest*, Research Report No. 6, US Army Tropic Test Center, Panama Canal Zone, February 1966.

[41]D. Dobbins, R. Chu, and C. Kindick, *op. cit.*

[42]A. Dubuisson and C. Kindick, *op. cit.*

acquisition performance for personnel targets appearing in tropical environments in daylight illumination. In all of these studies, as the target-to-observer range increased, the measure of acquisition performance showed progressive decrements. This was true for both aided (glasses with colored lenses) and unaided vision. However, the nature of this relationship was found to depend on the type of tropical forest in which acquisition occurred. In both the semideciduous-dry and the semideciduous-wet forests, a normal ogive function (e.g., see Figure 1) was found to best describe the relationship between the acquisition response and the target-to-observer range. On the other hand, in the evergreen-dry and the evergreen-wet forests, a linear function was found to best describe this relationship.[43] This later finding is somewhat unusual since in most acquisition research the normal ogive function is found to describe the relationship between the acquisition response and target-to-observer range. In the present case, it is likely that the linear relationship was caused by too few long ranges and too few short ranges.

Maxey and Caviness[44] found that under daylight conditions unaided target acquisition performance for personnel targets declined as target-to-observer range was increased to 100, 200, and 300 meters. Nearer targets were detected sooner than distant targets. Also, more of the nearer targets were detected than the distant targets. However, the absolute effect of distance depended upon the type of terrain in which targets appeared. In low- and mid-complexity terrains, the effect of

---

[43] D. Dobbins, R. Chu, and C. Kindick, *op. cit.*

[44] J. Maxey and J. Caviness. *Target Detection in the Field,* HumRRO Professional Paper 11-72, Human Resources Research Organization, Alexandria, Virginia, May 1972.

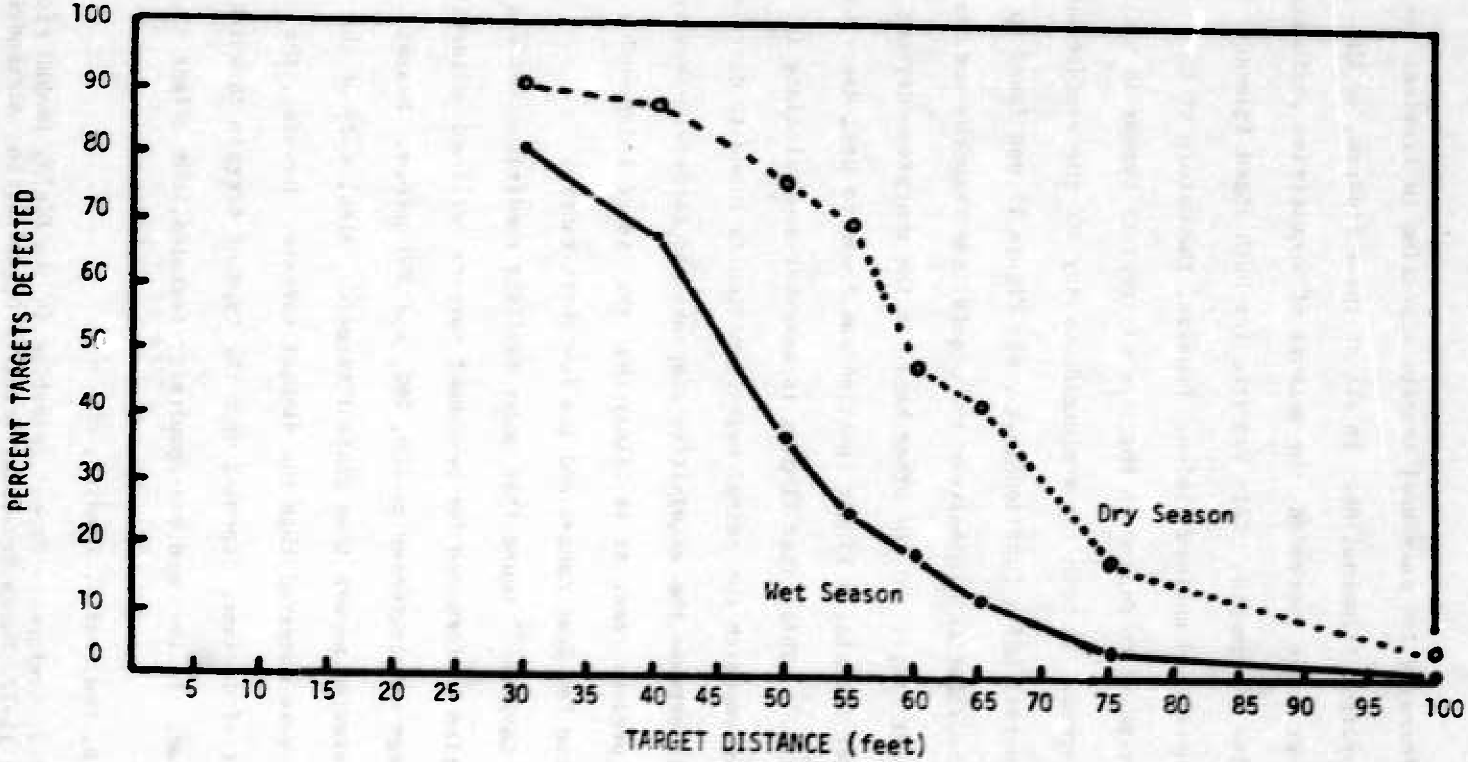


Figure 1. Comparison of visibility gradients in dry and wet seasons on the same three semideciduous forest sites.[45]

---

[45]Redrawn from D. Dobbins, R. Chu, and C. Kindick, *Jungle Vision VII: Seasonal Variation in Personnel Detectability in a Semideciduous Tropical Forest*, US Army Tropic Test Center, Panama Canal Zone, January 1967.

range was not as great as it was for high-complexity terrains. Terrain complexity in this study reflected the relative amounts and kinds of vegetation that existed in the terrains studied. The relationship between complexity and vegetation was direct, i.e., the more and varied the vegetation, the more complex the terrain was considered to be.

Hoffman[46] studied the detectability of a *Bundeswehr* jeep located at varying target-to-observer ranges by observers with and without visual aids under conditions of daylight illumination. For both modes of observation, the percentage of detections decreased with distance. However, it was found that with the visual aids (supported binoculars) detectability was greater at all ranges than without the aids.

Richardson[47] (in an analysis of the acquisition data collected for military vehicular and personnel targets under daylight illumination conditions for observers using binoculars) found that target-to-observer range significantly contributed to the prediction of acquisition performance. Stollmack and Brown[48] also found that target-to-observer range significantly contributed to the prediction of acquisition performance of ground observers for tank targets appearing in an open field area during daylight.

---

[46] H. Hoffman. *The Maximum Detection Range and Discovery of Land Vehicles*, Deutsche Forschungsanstalt fur Luft- und Raumfahrt, Institut fur Flugfuhrung, DFL 0475, April 1968.

[47] F. Richardson, *op. cit.*

[48] S. Stollmack and P. Brown. "Detection Time Analysis, in D. Howland and G. Clark (eds.), *The Tank Weapon System*, Report RF-573, Ohio State University Systems Research Group, Columbus, 1966.

Field studies conducted under conditions of low ambient illumination also find that target-to-observer range is an important factor in the acquisition process. For example, Humphreys and Gee[49] found for unaided observation that under full moonlight conditions the detection of standing and walking camouflaged personnel targets varied inversely with range to the targets. Taylor[50] found that for both full-moon and no-moon illumination, acquisition of personnel targets became progressively worse as target-to-observer range increased. Finally, a series of studies conducted by Sternberg and his associates at the Hunter-Ligget Military Reservation[51,52,53] also demonstrated the detrimental effect of increased target-to-observer range on acquisition performance. In these studies, the effect was demonstrated under various low ambient illumination conditions for observers with and without optical and electro-optical visual aids.

---

[49] A. Humphreys and D. Gee. "Experimental Design for User Review of Camouflage for the Individual Combat Soldier," in *Army Human Factors Engineering Conference*, Eighth Annual, Army Research Office, Office of Chief of Research and Development, Department of the Army, November 1962.

[50] J. Taylor, *op. cit.*

[51] J. Sternberg and J. Banks, *op. cit.*

[52] J. Farrell, J. Banks, and J. Sternberg. *Search Effectiveness with the Starlight Scope and 7x50 Binoculars*, Technical Research Report 1164, Behavior and Systems Research Laboratory, Office of the Chief of Research and Development, Arlington, Virginia, June 1970.

[53] J. Banks, J. Sternberg, J. Farrell, W. Dalhamer, and D. Vreuls. *Effects of Search Area Size on Target Acquisition with Passive Night Vision Devices*, Technical Research Report 1168, US Army Behavior and Systems Research Laboratory (BESRL), Arlington, Virginia, February 1971.

These studies all show the importance of target-to-observer range in the acquisition process. In general, the relationship between acquisition performance and the range variable is an inverse function. That is, at near ranges acquisition performance is superior to the performance obtained at far ranges. This relationship is reflected in the usual finding that the cumulative probability of response is related to target-to-observer range by the normal ogive function. However, as these studies show, response will often depend on other variables operating during the acquisition process, e.g., complexity of the terrain, the type of vegetation, mode of observation, etc. Thus, while the general effect of the range variable on the acquisition process can be specified, the exact relationship that will be obtained under a given set of circumstances will depend on the extent to which these circumstances interact with the range variable.

Target exposure. Target exposure refers to the length of time that a target is available for acquisition by an observer. The effect of this variable on the detection process has been studied extensively in the laboratory. This is because under field conditions it is extremely difficult to control exact exposure times, except when expensive and complex instrumented ranges are available. However, the findings from the few field studies that have been conducted correspond to the findings from laboratory studies: as exposure time is increased, acquisition performance improves. Further, most of this research has been oriented toward the study of briefly appearing targets. This is particularly important for this review, since most combat targets are available for detection for only short periods of time, e.g., seconds.

One example of the effect of variations in target duration on the detection process is provided in a survey of visual detection research conducted by Blackwell and Taylor.[54] In this research observers viewed circular targets of constant luminance which varied in size from .5 minutes of arc to 60 minutes of arc. These targets were presented against a background whose luminance varied from 10^{-6} to 10^{3} foot-lamberts. Target exposure for each combination of target size and background luminance was varied from 1 millisecond through 3 milliseconds, 10 milliseconds, 30 milliseconds, 100 milliseconds, 200 milliseconds, 330 milliseconds, to 1 second. For each target exposure time, threshold functions relating the 50 percent contrast threshold to each value of target size and background luminance were derived. Comparison of these functions across target exposure times indicated that as exposure time was increased, the 50 percent contrast threshold showed corresponding decrements. That is, as exposure time was increased, detection performance improved.

Similar results have been obtained in other laboratory studies. Synd r and Greening[55] (in a study of dynamic visual acuity) found that as exposure time was increased over values of 33 milliseconds, 67 milliseconds, and 100 milliseconds, the ability of observers to discriminate detail in moving targets increased. Similarly, Crawford[56] also studied

[54] H. Blackwell and J. Taylor, *op. cit.*

[55] H. Synder and C. Greening. *The Effect of Direction and Velocity of Relative Motion Upon Dynamic Visual Acuity*, C5-447/3111, Autonetics Division, North American Aviation, Inc., Anaheim, California, January 1965.

[56] W. Crawford. *The Perception of Moving Objects. I: Ability and Visual Acuity*, FPRC/Memo 150a, Flying Personnel Research Committee, July 1960.

dynamic visual acuity and found, for a constant velocity target, that as exposure time was increased through values of 400, 500, 600, and 700 milliseconds, acuity thresholds decreased.

Other laboratory research indicates that the effect of target exposure on the detection process is dependent on the intensity of the target (its brightness or luminosity) at the time of detection. For example, Clark (as reported in Dember[57]) studied the detectability of a circular target, subtending 18 minutes of arc, presented in the central fovea of the eye. Target exposure time was varied from approximately 1 millisecond to 1 second. The luminance of the target background was held constant at 10 foot-lamberts. For durations up to 20 milliseconds, the Bunsen-Roscoe Law[58] was found to adequately predict the brightness threshold required for detection. However, for durations between 20 milliseconds and 80 milliseconds, the contribution of time to the relationship flattened to a straight line. Finally, for values from 170 milliseconds to about 1 second, the relationship specified by the law again became valid. Similar results were obtained when the target background luminance was reduced to zero. In this case, the reciprocity between time and intensity extended up to about 100 milliseconds.

---

[57]W. Dember. *The Psychology of Perception*, New York: Holt, Rinehart, and Winston, 1965.

[58]The Bunsen-Roscoe Law states that for a specified exposure time (t), the amount of energy (k) required to elicit a response is given by the product of the target intensity (I) and the exposure time, i.e., $Ixt = K$.

Bishop studied the effect of target duration on the detection process as a function of target brightness.[59] He investigated the relative target brightness required for the detection and identification of various forms as a function of target duration. Targets in this study were presented over a range of time varying from 32 milliseconds to 4 seconds. From the observer's point of view, the targets were slightly greenish-white in color and subtended a visual angle of approximately 1.25 degrees. They were presented against a greenish-white background which was illuminated to a low photopic level of 1.5×10^{-4} lumens. Target brightness was varied over a range of values from 1.5×10^{-3} lumens to 100×10^{-3} lumens. Targets were projected on a rear projection screen via a slide projector. Overall, the conditions of the experiment were judged to approximate the visual requirements for the observation of a distantly located tank-sized target through a Starlight Scope with low ambient illumination.

It was found that the target brightness required for criterion detection and identification performance decreased as the target exposure time was increased from 32 milliseconds up to values from 100 milliseconds to 170 milliseconds. This reciprocity between target intensity and target duration appeared to follow the Bunsen-Roscoe Law. However, for exposure times greater than those in the range from 100 milliseconds to 170 milliseconds, the target brightness required for criterion performance remained relatively constant. Further, the value of target brightness required for criterion performance in this latter range of exposure times (170 milli-

---

[59] H. Bishop. *Effects of Information Load, Location, and Mode of Observation on Detecting and Identifying Brief Targets*, HumRRO Technical Report 72-30, Human Resources Research Organization, Alexandria, Virginia, October 1972.

seconds to 4 seconds) was significantly lower than the target brightness values associated with the exposure times in the range from 32 milliseconds to 170 milliseconds.

These findings taken together with Clark's previously discussed results, indicate that the acquisition of relatively short duration targets (those presented for less than one second) is highly dependent on the target brightness at the time of detection. In particular, these results indicate that the target brightness required for the acquisition of such targets is specified by the Bunsen-Roscoe Law. However, for targets with exposure times in excess of one second, all the results indicate that the target brightness required for acquisition is relatively independent of exposure time. These levels of target brightness are substantially lower than that required for targets appearing for less than one second. The impact of these results for target acquisition in the field are clear. Unless the target brightness of a short duration target meets or exceeds the value required by the Bunsen-Roscoe Law, the probability of detection will be quite small. However, for targets which are exposed for durations in excess of one second, this limitation does not apply. In these cases, it may be expected that acquisition will be possible for much lower target brightness values. The exact brightness value required for detection with targets exposed longer than one second will be a function of other situational factors such as target motion, target size, or background illumination.

The only field studies that could be identified which have investigated the effects of duration on target acquisition were completed under conditions of low ambient illumination. The findings of these studies, however, agree with those of laboratory studies: as exposure time is increased, acquisition performance is improved. For example, Farrell, Banks, and Sternberg[60] found for target exposures of 10, 20, 30, and 90 seconds that the percent targets detected with a Starlight Scope increased with increased exposure time. Further, this improvement occurred for targets at near (50 to 100 meters), mid (101 to 200 meters), and far ranges (201 to 300 meters). However, the improvement as a function of increased exposure time was larger for far targets than it was for near targets.

Banks and his associates[61] (during an investigation of the effects of search area size on acquisition performance) also studied the effects of target duration on the acquisition process. In this study observers acquired targets using night vision aids under starlight and full-moon illumination conditions. It was found that the cumulative number of targets detected over successive 15-second blocks of time increased in a reliable fashion over the time period allotted for search (two minutes). In the first few seconds of search, only small percentages of the targets were detected. However, by the last few seconds of search, most targets had been detected. Similar results were obtained by Sternberg and Banks[62] during an evaluation of several passive night vision devices conducted under starlight, half-moon, and full-moon illumination conditions. Further, in both of these studies, increases in the level of illumination improved the percent targets detected in each block of time, i.e., more targets were detected earlier.

---

[60] J. Farrell, J. Banks, and J. Sternberg, *op. cit.*

[61] J. Banks, et al., *op. cit.*

[62] J. Sternberg and J. Banks, *op. cit.*

These studies thus point out a direct relationship between target exposure time and acquisition performance. That is, increases in target exposure time are associated with improvements in acquisition performance. Therefore, in a given acquisition situation, it can be expected that acquisition performance will be facilitated as exposure time is increased, particularly in those situations where other conditions are relatively impoverished. However, as several of the studies reviewed in this section indicated, there is considerable variation in the exact manner in which exposure time affects acquisition performance due to the effect of other variables. For example, the acquisition of short duration targets is improved if target brightness is increased. On the other hand, if the level of ambient illumination is reduced, target duration must be increased substantially for a marked improvement in acquisition performance.

Target motion. The effect of target motion on acquisition performance has been well studied in field investigations. Generally, the study of this variable has focused on (a) the effect of the presense *versus* the absence of target movement, and (b) the effect of target speed on the acquisition process.

In general, it has been found that target movement facilitates target detection. Anstey[63] measured the horizontal distance over which a camouflaged target could be seen in a tropical forest. Two methods of observation were employed: (a) targets moved away from a stationary observer until the observer could no longer see the targets, and (b) targets

---

[63] R. Anstey. *Visibility in a Tropical Forest*, Special Report S-3, Earth Sciences Division, US Army Natick Laboratories, Natick, Massachusetts, August 1963.

were prepositioned and motionless in random locations. In the latter method of observation, observers could move while they searched for targets. It was found that targets moving away from the observer were seen at significantly further distances than prepositioned targets. Similar results were found by Mattimore and Wollanston for targets in a mid-latitude forest in Sudberry, Massachusetts.[64] Finally, in a study of the detection of moving targets in a tropical forest, Dobbins and Kindick[65] reported that observers indicated the detection of target movement first directed them to the target, i.e., the target motion was the primary cue for the detection of these targets.

The above studies were conducted under conditions of daylight illumination. Studies conducted under conditions of night illumination have also found that moving targets are more easily acquired than stationary targets. For example, in a study conducted by the Japanese Infantry School,[66] it was reported that stationary targets were less detectable than moving targets. In this study, both single personnel targets and patrol-sized targets were detected at further distances when they were moving than when they were stationary.

However, in a study conducted at Fort Benning under conditions of full-moon illumination, Humphreys and Gee[67] found that the detection rate for walking targets was lower than for standing, motionless targets. In this investigation the observers were seated about 60 feet [18 meters]

---

[64]R. Anstey, *op. cit.*, November 1964.

[65]D. Dobbins and C. Kindick, *op. cit.*

[66]"Principles of Night Combat," *op. cit.*

[67]A. Humphreys and D. Gee, *op. cit.*

above a very large, open grass-covered field. Targets (military personnel dressed in camouflage uniforms) were presented in this open field at varying distances (100 to 250 meters) in front of each observer. Observers were given two minutes in which to detect targets. During this observation period the targets either remained in place or moved around in the general area of the position that they held at the beginning of the observation period. Thus, the viewing conditions provided observers in this study were relatively favorable for nighttime target acquisition. However, as indicated above, the walking targets were detected at substantially lower rates than the stationary targets. While the basis for this paradoxical finding is not clear, it does suggest that under some conditions target motion will not necessarily facilitate the acquisition process.

Banks and his associates[68] found that under conditions of low illumination and a large search area, the detection rate for stationary and moving targets did not appreciably differ. However, for small search areas, moving targets were detected at a higher rate than stationary targets. Acquisition in this study was mediated by several passive night vision devices.

Taken together, these two studies suggest that the effect of target motion under conditions of low illumination may be moderated by the size of the area that must be searched. However, the overall pattern of results from these field studies suggest that target motion can, under the proper conditions, facilitate the acquisition of targets by ground observers.

---

[68] J. Banks, et al., *op. cit.*

The question addressed by the studies reviewed above concerned only the effects of motion, *per se*, on the acquisition process. An ancillary question in this regard involves the rate at which this motion occurs. In particular, it is important to determine to what extent variations in target speed affect the acquisition process. Only two studies conducted under field conditions have addressed this question. Overall, it was found that as speed was increased, acquisition performance increased. Stollmack and Brown[69] found that the crossing velocity of tank targets was directly related to detection rate and inversely related to detection time. Maxey and Caviness[70] reported a similar finding for personnel targets appearing in three types of terrain (low, medium, and high complexity) moving at a walk, slow run, and a fast run. However, they found that target speed interacted with terrain complexity in the following way: For targets appearing in the highly complex terrain, increases in target speed brought about significant reductions in the time required for acquisition; while for targets appearing in the low complexity terrain, increases in target speed brought about only slight reductions in the time required for acquisition. The results for the medium complexity terrain fell in between those for the high and low complexity terrains.

These studies thus show, in general, that both the presence of motion and the rate at which this motion occurs act to facilitate the accomplishment of the acquisition task. They also demonstrate that (as was found to be true with other variables reviewed in this section of the report) the

[69] S. Stollmack and P. Brown, *op. cit.*

[70] J. Maxey and J. Caviness, *op. cit.*

particular effect of target motion on acquisition may be moderated by the operation of other variables in the acquisition situation.

Environmental Characteristics

The previous sections of this review have addressed the effects of selected target characteristics on the acquisition process. However, targets always appear in the context of an environment. As a consequence, it may be expected that certain of the characteristics which define a particular environment wi.'' likely affect the acquisition of targets. Among these characteristics are: clarity of the atmosphere, level of ambient illumination, terrain, presence and types of vegetation in the environment, target location, position of the illuminant, and ambient temperature. It is the purpose of this section of the review to discuss the effects of these characteristics on the acquisition process.

The atmosphere. The atmosphere, which is normally thought of as "air," is a colloidal suspension of particles in a mixture of gases (oxygen, nitrogen, carbon dioxide, hydrogen, and a variety of inert gases), including water vapor. The nature of the particles in suspension varies according to time, location, and altitude. It has been shown that pure, dry air is an almost perfect medium for the transmission of optical images in the visible light spectrum. In particular, the visibility in such an atmosphere is somewhat more than 200 miles.[71] Howeve', such a pure medium never exir's in the natural world. Thus, optical transmission through the atmosphere is limited by the presence of particles of matter in the atmosphere.

---

[71] J. Wulfeck, et al. *Vision in Military Aviation*, WADC Technical Report 58-399, Wright Air Development Center, US Air Force, Wright-Patterson AFB, Ohio, November 1958.

The particles of matter that act to effect the transmission of light through the atmosphere are water (in its various forms), smoke, dust, and industrial pollutants. Typically, particles of matter concentrate in patches or layers in the air. When these concentrations are dense they are labeled (depending on the composition) as haze, clouds, or fog.

One consequence of the presence of these particles of matter in the atmosphere is that light reflected from an object is attenuated. Light from other sources is also added to light reflected from an object. This is because the atmosphere tends to scatter and absorb reflected light and, in addition, it tends to scatter daylight illumination along observer lines-of-sight. Two examples can illustrate these processes.

Assume two personnel targets, both wearing light colored uniforms, are viewed against a bright homogeneous sky background such that one is seen at a near point while the other is viewed at a far point. If there is a slight haze, the distant target will appear to be only slightly brighter than the sky background. Since the apparent background is the same for both targets, some of the light from the distant target must have been lost or attenuated in passing through the atmosphere.

Now assume that the two targets have exchanged their light colored uniforms for dark colored uniforms and have returned to their respective positions. The near target will now appear darker than its background, but the far target will appear only slightly darker than its background. This results implies that light from the atmosphere was scattered toward the observer.

Thus, it can be seen that the atmosphere acts in two ways to reduce the contrast of targets viewed at a distance. In fact, research conducted by the Tiffany Foundation[72] found that this reduction occurs exponentially as a function of target range and the particular transmittance properties of the atmosphere in the region in which the acquisition task is being conducted. Further, these studies showed that the reduction in apparent contrast by the atmosphere was dependent upon the condition of the atmosphere as discussed above. For example, the reduction in contrast was less at all ranges for a clear day with a light smoke than for a hazy day on which cloud coverage was 70 percent (as estimated by the experimenter).

Thus, it is clear that the manner in which the atmosphere transmits light reflected from a target can affect the detectability of the target by attenuating the contrast of the target with its background. However, it is not clear to what extent this property of the atmosphere is important for the acquisition of ground targets in field situations. This is because studies of the effects of the presence of dust, fog, haze, rain, smoke, and snow on the visibility of military targets are virtually nonexistent. During the course of the review of the literature, only two studies were discovered which addressed the effects of the atmosphere on the acquisition of military targets.

During a service test of the night vision sight, crew-served weapons, AN/TVS-5 (second generation),[73] ten observers attempted to observe stationary personnel and vehicular targets under conditions of fog at

---

[72] J. Conant, et al. *Visibility Studies and Some Applications in the Field of Camouflage*, Summary Technical Report, Division 16, National Defense Research Committee, Washington, D.C., 1946.

[73] L. Walton. *Service Test of Night Vision Sight, Crew-Served Weapons, AN/TVS-5 (Second Generation)*, AIB 73-561, Partial Report, US Army Infantry Board, Fort Benning, Georgia, February 1973.

several target-to-observer ranges. It was not clear what condition of ambient light was employed in this phase of the service test. However, no targets were detected by any observers.

Hoffman[74] (in a study of the acquisition of a *Bundeswehr* jeep under various conditions of illumination using both aided and unaided observation) investigated the effects of horizontal standard visibility (a measure of atmospheric clarity) on acquisition performance. For daylight illumination and unaided observation, he found that the maximum distance at which the jeep could be detected was relatively constant (between 1000 and 2000 meters) for measured meteorological visibility distances in the range from 8 to 56 kilometers. However, for daylight illumination conditions and aided observation (15x60 field glasses), the maximum distance at which the jeep could be detected increased as the measured meteorological visibility increased from 8 kilometers (in 8-kilometer increments) to 56 kilometers. At the lower meteorological visibility ranges, the differences between the maximum detection distance for the jeep were small for unaided versus aided observation. However, at the higher meteorological visibility ranges, the differences in the maximum detection range became greater with aided acquisition being superior.

For twilight illumination conditions, the results for the acquisition of the jeep by observers were somewhat different. As the atmospheric visibility increased, the maximum distance at which the jeep was detected increased for both aided and unaided vision. Further, aided vision was always superior to unaided vision at each level of atmospheric visibility. However, as the level of ambient illumination decreased, the effect of variations in atmospheric clarity diminished.

---

[74] H. Hoffman, *op. cit.*

These two field studies show that the condition of the atmosphere clearly is important for the acquisition of military targets for both day and night acquisition. In addition, the lack of studies in this problem area clearly points to the need for research into the effects of smoke, rain, snow, and other atmospheric conditions on the acquisition of military targets.

Illumination. As discussed in a previous section of this review, the receptors of the eye are sensitive to energy in the electromagnetic spectrum from about 380 to 760 nanometers in wavelength. Further, it was pointed out that the eye is differentially sensitive to different levels of ambient illumination at each of these wavelengths due to the existence of two different kinds of receptor organs in the retina of the eye. One set of receptors (the cones) mediates photopic of "daylight" vision, while the other set (the rods) mediates scotopic or "night" vision. The conditions for photopic vision occur when the luminance of an object, i.e., the intensity of the reflected light, is approximately 10 millilamberts and above. The conditions for scotopic vision occur when the luminance of an object is approximately 10^{-1} millilamberts and below. For luminance levels between 10^{-1} and 10 millilamberts, both the rods and cones are operative and vision is said to be mixed (mesopic).[75]

An additional factor to be considered with respect to the effect of light on the eye is the state of adaptation of the eye with respect to the intensity of the light. At any given moment the eye is either light

---

[75] L. Riggs. "Light as a Stimulus for Vision," in C. Graham (ed.), *Vision and Visual Perception*, New York: John Wiley, 1965.

or dark adapted or is in the process of adaptation. Adaptation refers to the fact that, under stimulation by light, the retina progressively loses its sensitivity to light, while in the absence of light the retina regains its sensitivity.[76] Under normal conditions of illumination, thresholds for the detection of light are much higher than for lower levels of illumination. If the eye is kept in darkness for progressively longer periods of time, the threshold for light detection drops. If this process is continued for approximately 30 minutes, the eye become maximally responsive to light, i.e., light detection thresholds reach a minimum level. This adaptation occurs first for the cones and then for the rods in the retina of the eye. The impact of this phenomenon for target acquisition is that the observer's eye must be adapted to the illumination conditions of the acquisition task before reliable acquisition performance can be measured.

The level of ambient illumination in a given geographical area, i.e., the amount of light incident on this area, is dependent, for the most part, on the time of day and the extent to which incident light is attenuated by cloud cover or other meteorological phenomenae. Table 1 presents approximate levels of ambient sky illumination measured in foot-candles for the day and night sky under various conditions. From this table it can be seen that the level of scene illumination varies from relatively high levels ($1 - 1.3 \times 10^4$ foot-candles) to relatively low levels (1.0×10^{-5} foot-candles) as the conditions change from daytime with direct sunlight and no cloud cover to nighttime with starlight and cloud cover.

---

[76] F. Geldard, *op. cit.*

Table 1. Ambient Illumination for Day and Night Sky Under Various Conditions[77]

Day/Night Conditions	Ambient Illumination Level (Foot-Candles)
Full Daylight (Direct)	$1 - 1.3 \times 10^4$
Full Daylight (Indirect)	$1 - 2.0 \times 10^3$
Overcast Day	1.0×10^2
Very Dark Day (Sunrise/Sunset)	1.0×10^1
Twilight	1.0×10^0
Deep Twilight	1.0×10^{-1}
Full-Moon	1.0×10^{-2}
Quarter-Moon	1.0×10^{-3}
Starlight (Clear)	1.0×10^{-4}
Starlight (Overcast Sky)	1.0×10^{-5}

[77] D. Jones, et al, *op. cit.*, p. 3-44.

In particular, it is to be expected that target acquisition performance, under conditions of low ambient illumination (e.g., those levels which typically occur during the nighttime hours), will be inferior to the performance obtained under conditions of high ambient illumination (e.g., those levels which typically occur during the daytime hours). Field studies bear out this conjecture. For example, researchers of the Vertex Corporation[78] found (during the verification test of a combat system model for ground-based operations) that the average detection range for personnel targets was significantly greater for daylight targets than it was for targets appearing under night conditions (122 *versus* 60 meters). Researchers at Fort Hood, Texas,[79] reported a similar finding. During a field test these workers investigated the capability of armored cavalry troops to complete surveillance and target acquisition tasks under day and nighttime operational conditions. The results of the evaluation indicated that night performance was degraded by 30 percent when compared to day performance in the areas of surveillance, target acquisition, and cross-country movement.

However, the results of these studies represent comparisons of performance for only grossly defined illumination conditions which presumably differed from each other by a substanial margin. Unfortunately, such results do not indicate if acquisition performance can be expected to show improvements as the level of ambient illumination is increased over

[78] H. Childers, R. Shook, E. Fellin, P. Lerch, and P. Michelsen. *Verification Report for SIAF System: Report of Test*, SIAF Report No. 21, The Vertex Corporation, Bethesda, Maryland, September 1971.

[79] *Armored Cavalry Troop Test*, Executive Summary, United States Army, January 1972.

all illumination levels likely to be encountered in natural field settings. From the results of laboratory and field investigations to be discussed below, it does appear that there is some limitation in the amount of improvement that can be expected in acquisition performance as illumination is increased. In particular, these studies indicate that acquisition performance is affected more by variations in illumination during conditions of low ambient lighting (less than one foot-candle) than during conditions of moderate to high ambient lighting (greater than one foot candle).

Chapanis[80] has discussed the relationship between visual acuity (the ability to resolve small objects and to distinguish fine detail) and background luminance in some detail. In this discussion, a curve representing the data of six investigations on visual acuity as a function of background luminance was presented. This curve related the actual size of the smallest detail that could be detected by observers as a function of background luminances from -3 log millilamberts to 4 log millilamberts. This curve is reproduced in Figure 2. Two important results are presented by this function. First, as background luminance was increased from -3 log millilamberts to about 0 log millilamberts (10^{-3} millilamberts to 1 millilambert), substantial improvements occurred in the smallest visual angle that could be detected. Second, as background luminance was increased from about 0 log millilamberts to 4 log millilamberts (1 millilambert to 10,000 millilamberts), there was very little or no improvement

---

80 A. Chapanis. "How We See: A Summary of Basic Principles," in *A Survey Report on Human Factors in Undersea Warfare*, prepared by the Panel on Psychology and Physiology, Committee on Undersea Warfare, National Research Council, Washington, D.C., 1949, pp 3-60.

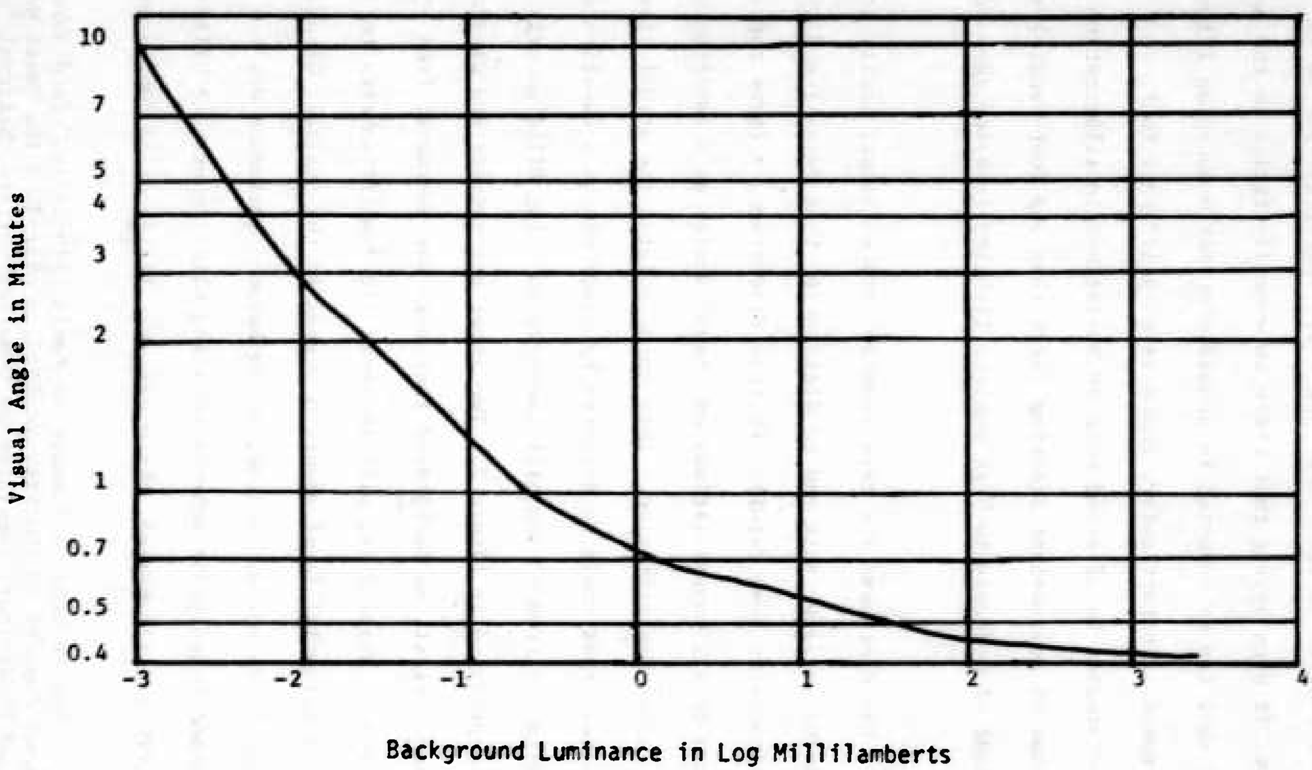


Figure 2. Smallest detail visible as a function of background luminance.[81]

---

[81]Redrawn from Figure 19, p 29, Chapter 1, in A. Chapanis, "How We See: A Summary of Basic Principles," in *Human Factors in Undersea Warfare*, National Research Council on Undersea Warfare, Washington, D.C., 1949.

in the smallest visual angle that could be detected. These results thus suggest that substantial improvements in acquisition performance may be expected for only luminance values in the lower ranges of background luminance. Further, they indicate that for the upper values of background luminance, successive increments in luminance can be expected to have only minimal or no effect on acquisition performance in field settings. Field research supports these conclusions.

For example, Dobbins and his associates have found no consistent relationship between variations in daylight illumination (measured in foot-candles) and the detection performance of observers for camouflaged personnel in tropical forest environments.[82] In these studies the average horizontal illumination varied from 12 foot-candles to 194 foot-candles measured at the observer's eye. When observers were tested in the morning and later in the afternoon, it was found that even though there were significant changes in light levels, there were no corresponding changes in detection performance.

On the other hand, field investigations conducted under low ambient light conditions find that increments in illumination level generally have substantial beneficial effects on target acquisition performance. For example, the Japanese Infantry School study cited previously[83] found that the range at which single and multiple personnel targets were detected increased substantially as the night illumination level increased from starlight through one-quarter, one-half, and three-quarter phases to

---

[82] D. Dobbins, R. Chu, and C. Kindick, *op. cit.*

[83] "Principles of Night Combat," *op. cit.*

full-moon illumination. Further, comparing the results of the starlight conditions with those of the full-moon conditions showed that in most cases the relative improvement ranged from 200 to 400 percent.

Similar results were obtained by Taylor[84] in a study of no-moon *versus* full-moon illumination. He found that the full-moon condition extended the range of observation approximately three times that of the no-moon condition (85 meters *versus* 28 meters). Targets in this study were infantry soldiers and observation data were obtained on clear nights.

Hoffman[85] also found (in a study of the detectability of a *Bundeswehr* jeep) that illumination level affected target acquisition. In his study it was found that the maximum detection range of the jeep decreased during twilight as a direct function of decreases in brightness of the target background when brightness decrements were plotted on a logarithmic scale. This was true for both unaided and aided (10x50 and 15x60 field glasses) vision.

Farrell and his associates[86] found (in a study of search effectiveness with the Starlight Scope) that as the illumination level increased from clear starlight to full-moon illumination, the percent targets detected using the Starlight Scope increased from 25 to 68 percent. The greatest gains in performance occurred at the lower light levels as compared to the higher light levels. For example, percent detections increased from 25 to 38 percent (relative gain of 52 percent) as the

---

[84] J. Taylor, *op. cit.*

[85] H. Hoffman, *op. cit.*

[86] J. Farrell, J. Banks, and J. Sternberg, *op. cit.*

illumination level went from an average of 1.9×10^{-4} foot-candles (clear starlight) to an average of 6.3×10^{-4} foot-candles (cloudy starlight plus reflected ground light). When illumination was increased from an average of 24×10^{-4} foot-candles (half-moon) to an average of 100×10^{-4} foot-candles (full-moon), the percent detection only increased from 59 to 68 percent, a relative gain of 15 percent. Further, this study showed that increases in the level of illumination significantly improved the detectability of faraway targets more than it improved the detectability of near targets. Also, it was found that exposure time and level of illumination jointly acted to affect target detectability. In general, as both exposure time and illumination level increased, target detectability improved with the lowest percentage of targets being detected at short exposure and lower illumination levels and the highest percentage of targets being detected at the long exposure and higher illumination levels.

Sternberg and Banks[87] also found that as the ambient illumination level increased, target acquisition performance improved. This study employed several passive night vision devices (the Miniscope, the Starlight Scope, the Crew-Served Weapons Sight, and the Night Observation Device: Medium Range). For each of the night vision devices the percentage of targets detected increased, while the time to detection decreased as the level of ambient illumination rose from an average of 9.7×10^{-5} foot-candles (starlight) through an average of 140×10^{-5} foot-candles (half-moon) to an average of 1100×10^{-5} foot-candles (full-moon). Further, on the average, increases in illumination level improved target acquisition at far distances more than at near distances.

---

[87] J. Sternberg and J. Banks, *op. cit.*

In this study two kinds of targets were studied: small personnel targets at near and mid ranges, i.e., 100-350 meter and 350-800 meter distances, respectively, and large vehicular targets at mid and far ranges, i.e., 350-800 meter and 800-1200 meter distances, respectively. In general, for all devices, both vehicular and personnel target detection showed substantial improvement as illumination level increased. However, detection of personnel targets showed more relative improvement than detection of vehicular targets as the illumination level increased.

Banks and his associates studied the effects of varying the size of the area to be searched during target acquisition.[88] Banks, et al., found that increases in the illumination level from an average value of 1.1×10^{-4} foot-candles (starlight) to an average of 91×10^{-4} foot-candles (full-moon) improved target detection performance for all sector sizes studies (25, 35, and 75 degree sectors). This was true for observation using the Starlight Scope, the Crew-Served Weapons Sight, and the Night Observation Device: Medium Range. Further, this improvement was greater for targets with short exposures as compared to targets with long exposures.

Finally, in a study of the effects of improved training on visually aided target acquisition performance, Banks, Sternberg, Cohen, and Debow[89] found that as illumination level increased (from starlight to full-moon illumination), the percentage of targets detected increased. This was

---

[88] J. Banks, *op. cit.*

[89] J. Banks, J. Sternberg, B. Cohen, and C. Debow. *Improved Search Techniques with Passive Night Vision Devices,* Technical Research Report 1169, US Army Behavior and Systems Research Laboratory (BESRL), Arlington, Virginia, February 1971.

true for both types of training investigated (special and standard) and as well for the two visual aids studied (Starlight Scope and the Night Observation Device: Medium Range). In addition, for both visual aids the relative improvement due to the special training was greater for starlight illumination than for full-moon illumination.

The above studies all consistently show that increases in the illumination level are generally accompanied by improvements in target acquisition performance. Further, they show that this is true for both aided and unaided observation. In addition, these studies indicate that illumination level may interact with other acquisition parameters to affect the acquisition process. For example, increases in low level illumination seems to improve the detection of faraway targets more than the detection of nearby targets. Also, the detection of short exposure targets seems to be more improved by increments in illumination level than the detection of long exposure targets. This finding is in line with the results for other previously discussed acquisition studies of situations where two or more factors influencing acquisition were operative.

Overall, the results of the studies reviewed in this section indicate that as the level of ambient illumination is increased from relatively low levels (e.g., starlight illumination) to moderately low levels (e.g., full-moon illumination), substantial improvements in target acquisition performance occur. Further, these results indicate that as the ambient illumination level is increased from relatively moderate levels (e.g., early morning light) to higher levels (e.g., full daylight), little or no significant improvement in target acquisition performance is likely to occur. This can be seen by comparing the results of the Japanese

Infantry School and the Taylor studies with the results of Dobbins, Chu, and Kindick. In the former case, improvements in acquisition performance of 300 and 400 percent were found as illumination level went from starlight to full-moon levels. However, in the latter case, no significant improvement in detection performance was obtained as illumination level varied from morning to afternoon levels. Thus, it seems clear that illumination level is a more important variable for low illumination acquisition than for high illumination acquisition performance.

Terrain. It is an obvious fact that the earth's surface varies considerably in terms of its topography. This variation may be studied with respect to a relatively small, local terrain area in terms of the effect of intrinsic or unique terrain features on target acquisition. Also, it may be studied with respect to several geographically distinct areas in terms of the effect of gross differences among these areas on target acquisition. With respect to the problem of target acquisition in natural settings, however, two such factors (landform relief and vegetative coverage) have direct relevance to the acquisition process. This is due to the fact that variations in either of these factors (separately or together) may be expected to affect (a) the nature of the background against which targets will appear and, hence, target/background contrast, (b) the maximum distance at which various military targets (either stationary or moving) can possibly be acquired, (c) the amount of time a moving target will be unmasked and, thus, available for acquisition, and (d) the extent to which a target will be obscured.

It is apparent that each of these terrain factors reflects a unique aspect of the earth's topography in given geographical areas. For example, the relief (the irregularities or elevations of a land surface) of a specific geographic area may be flat in some places, rolling in others, and quite hilly in still other places. Similarly, some geographic areas may be covered in tall grasses and shrubs with a few small trees, while other areas may be covered in tall underbrush and interspersed with groves of tall trees. However, the relief and vegetative coverage of a geographical area are typically correlated, as both are dependent upon climatic and geological factors characteristic of the area. Examples of such factors are (a) the drainage system of the area, (b) the annual temperature and rainfall of the area, and (c) the nature and composition of the soil found in the area. Thus, in studying the effect of terrain variation on the acquisition process, it is necessary to be aware and to take into account the possibility of significant dependencies between relief and vegetative coverage.

The fact that significant dependencies may exist between the relief and vegetative coverage of a geographic area has generally been recognized by researchers working in this area. As a consequence, many of these researchers have taken a holistic approach in their study of terrain effects on the acquisition process. In such studies the effect of terrain on performance has been investigated through comparisons of the acquisition performance obtained in areas which were objectively very different in terms of both relief and vegetative cover or which were subjectively judged to be very different by either the experimenter or groups of judges.

For example, Stollmack and Brown[90] studied the effect of terrain on the acquisition of tank targets by ground observers. In this study moving

[90] S. Stollmack and P. Brown, *op. cit.*

tanks appeared in a variety of terrain areas judged to vary in terms of a subjective construct labeled "scene complexity." Conceptually, scene complexity was defined in terms of the presence and number of environmental factors judged as likely to partially or totally conceal a target. Operationally, scene complexity was measured in terms of the number of avenues of approach along which a tank could advance toward an observer. Thus, for this study, a low complexity scene (and therefore a low complexity terrain) was characterized by the presence of few terrain features and only a limited number of approaches. A high complexity scene (and therefore a high complexity terrain) was characterized by the presence of many terrain features and many avenues of approach. The results of the study indicated that as the complexity of the scene (and thus the terrain) increased, the number of tank targets acquired per unit time decreased. These results indicate that as the number of terrain features (irregularities and vegetation) obstructing vision increase, acquisition performance will show progressive decrements.

Similar results were obtained by Maxey and Caviness[91] in a study of the acquisition of moving personnel targets by stationary observers. In this study the effect of terrain on acquisition performance was assessed by having separate groups of observers acquire targets in three objectively different terrains. In the first terrain area (labeled the low complexity terrain), the vegetation was sparse and offered little concealment; it was covered with tall grasses and a few small pine trees. In the second terrain area (labeled the medium complexity terrain), there was much more

[91] J. Maxey and J. Caviness, *op. cit.*

vegetation and concealment was more plentiful; it was covered with tall grasses and was overgrown with bushes and larger pines. Finally, in the third terrain area (labeled the high complexity terrain), the vegetation was greatly overgrown and concealment was extremely plentiful; tall bushes abounded and there was a mixture of large pines and deciduous trees. In addition, the relief of the first two terrain areas was generally quite flat with few irregularities, while the relief of the third terrain area was generally rolling with many surface irregularities.

The terrain areas studied in this investigation were chosen by the experimenters on the basis of the obvious differences described above. As a check on this selection, Maxey and Caviness had a group of judges (selected from the same population as the observers who completed the acquisition task during the study) rate the complexity of these terrains. The observers were instructed to judge the ease with which personnel targets could be detected in these terrain areas. Analysis of these ratings revealed that the judges and the experimenters were in good agreement with respect to the judged complexity of each terrain.

Analysis of the detection data (time required for detection) collected in each of the three terrain areas revealed that as terrain complexity increased, the time required for detection of moving personnel targets also increased. Thus, in this case, the presence and numerosity of terrain features (as this was reflected in the variations among the terrain areas studied) were also found to restrict the detectability of targets.

James and James[92] have also studied the effect of terrain differences on the acquisition of ground targets. These researchers conducted two studies in varying geographic localities. In the first study they found that the average visibility distance for a human target dressed in an OG-107 parka shell was greatest for an open coniferous forest (250-300 feet [80-90 meters]), next greatest for a chaparral area (95 feet [30 meters]), and least for a dense coniferous forest (65 feet [20 meters]). In the second study they found that a human target dressed in the OG-107 parka shell was detectable at longer ranges (820 feet [250 meters]) in an oak woodland dominated by valley and interior live oak trees than in a chaparral area dominated by chamise, yerba senta, buckbrush, and manzanita species (40 feet [12 meters]). Thus, these results also indicate that as the obstructions to visibility provided by the physical features of an area (such as vegetation) increase the acquisition performance of an observer will show substantial decrements.

Researchers of the Vertex Corporation[93] have collected data which also agree with this conclusion. In 1969, data were obtained which attempted to specify the ranges at which enemy personnel targets were acquired in South Vietnam jungle environments. Later, in 1970, additional data were collected during the SIAF field tests in Hawaii for specifying the detection ranges of personnel targets appearing in open, brush, and jungle environments. Finally, during the verification test of the Vertex

[92] J. James and W. James. Unpublished study reported in R. Anstey, *Visibility Measurement in Forested Areas*, Special Report S-4, Earth Sciences Division, US Army Natick Laboratories, Natick, Massachusetts, November 1964.

[93] H. Childers, et al., *op. cit.*

SIAF mathematical model at the Hunter-Ligget Military Reservation in 1971, data were collected on the detection ranges of personnel targets appearing in an open area with few trees. In general, the results of these data collection efforts indicated that as the restrictions to visibility decreased, the detectability of personnel targets increased. For example, targets appearing in open areas were detected at longer ranges than in either jungle or brush environments.

The above studies were conducted under conditions of daylight illumination. The results of these studies were consistent with respect to the effect of terrain on target acquisition. In all cases it was found that target acquisition performance was significantly affected by the type of terrain area in which this performance was measured. Further, these studies indicate that the major factor underlying this effect of terrain was the number and extent of the obstructions to visibility provided by the relief and/or vegetative cover characteristic of the terrain areas studied. In particular, it was found that as the complexity of the terrain (defined in either objective or subjective terms) increased, target acquisition performance showed progressive decrements.

It is expected that similar results would be obtained for the effect of similar terrain variations on acquisition performance under conditions of low ambient illumination. Unfortunately, no studies were located which dealt directly with this problem. As a consequence, it is not possible at this time to make any specific statement about the effect of terrain variations on target acquisition under low ambient lighting conditions.

The above cited studies all dealt with the effects of between-terrain variations on target acquisition performance. However, within a given geographic area, it can be expected that there will be local variation in the landform relief and/or vegetative cover. Depending upon how targets are placed and come to behave with respect to local variations in these factors, it may be expected that they will interact with these variations to influence their detectability either positively or negatively. Thus, local variations in relief and vegetative cover are also likely to be important factors in the acquisition process. Field studies support this conclusion.

Eckles and his associates[94] observed (in a study of the effects of mobility and agility on target acquisition by tank gunners) that the relief structure and vegetation of their test area served to interrupt the gunner's view of the target so that targets were exposed for only very short durations. In addition, relief structure and vegetation served to reduce the effective size of targets through partial obscuration.

A similar finding was reported by Caviness and Maxey[95] in a study of the acquisition of advancing personnel targets by stationary observers. In this investigation, targets wore three different types of uniforms (forest green, olive drab, and black) and appeared against two similar terrain backgrounds. The results of the study indicated that the relative detectability of the forest green uniformed targets varied as a function of the background against which they were observed. As the background changed, the detectability of these targets decreased. However, the

---

[94] A. Eckles, T. Garry, W. Mullen, and H. Aschenbrenner. *HELAST II*, Technical Memorandum 12-73, US Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, 1973.

[95] J. Caviness and J. Maxey, *op. cit.*

relative detectability of black and olive green uniformed targets remained essentially the same. Since the change in background only affected the detectability of the forest green targets, it seems likely that these results were due to the interaction of the forest green targets with some specific terrain feature (or features) present in one background but not in the other background. Caviness and Maxey suggested these results were due to slight differences in the local relief and vegetative cover that existed between the two backgrounds, as well as target/background color and brightness contrast.

Thus, it seems clear that both inter- and intra-terrain variations can affect the detectability of targets. It may be expected for different terrain areas located in geographically separate areas that a major effect of terrain will be in terms of target obscuration and the maximum distance at which targets can possibly be acquired. Further, it may be expected for a given terrain area that specific features of the area will likely influence target detectability through interactions with specific target characteristics, such as contrast and target duration. The effects of these interactions may be facilatory or inhibitory. However, the relative importance of inter- and intra-terrain variations needs to be studied further. Far too little literature exists in this area with respect to ground target acquisition. As a consequence, it is possible to draw only the most general conclusions about the effect of overall terrain variations on the acquisition process.

Vegetation. In the previous section the overall effect of terrain on the acquisition process was reviewed. It is the purpose of this section of the review, however, to consider the effects of variations in vegetation cover on target acquisition. The effects of vegetation have been well researched with respect to its effect on the acquisition process. Further, this feature is particularly important from a practical point of view, since it may be expected in future combat situations (at least in the initial stages) that vegetation will be a prominent feature of the modern battlefield.

In areas where adequate sunlight and moisture are available, some form of plant life grows. However, as a consequence of seasonal variations in sunlight and moisture, the amount and nature of plant life shows substantial variation over time. Thus, it may be expected that detectability through vegetated areas will vary with time to the extent that the vegetation in these areas affects detectability and is itself variable with season.

Only a few field studies have investigated the effects of seasonal variation on detectability in vegetated areas. In the first of these, Drummond and Lackey[96] measured the visibility of a six-foot, man-sized target covered in canvas cloth dyed a medium dark green (shade OD 8). Detectability was studied during both summer and winter in 91 stands of deciduous forest. The target was chosen to correspond to the dimensions of a soldier plus his military equipment. The forest stands were all located in the central region of the United States. Observations were made on clear days when the sun was high. Overall, detectability (in terms of detection distance) in deciduous stands averaged 37 percent less in the

---

[96] R. Drummond and E. Lackey. *Visibility in Some Forest Stands of the United States*, Technical Report EP-36, Quartermaster Research and Development Command, Natick, Massachusetts, May 1956.

summer than in the winter. In the winter the average detection distance was 75 yards [69 meters], while in the summer the average detection distance was only 47 yards [43 meters]. However, no differences in the average detection distance were found in evergreen stands as a function of seasonal variations. For these stands the average detection distance was 49 yards [45 meters], both in the summer and the winter.

The forest stands in this study were classified in terms of the height and continuity of both the primary growth (trees) and the undergrowth (bushes, shrubs, and grasses). For stands composed of medium height trees (30 to 75 feet tall [9 to 23 meters]) with touching branches, sufficient data were collected by Drummond and Lackey to allow comparisons between stands with undergrowths of different heights as a function of seasonal variations. These comparisons revealed overall that as the height of the undergrowth decreased, the average detectability of a standard visibility object (a man-sized target) increased. However, the magnitude of this increment in detectability depended on the height of the undergrowth. For example, when the undergrowth was between six and 30 feet [2 and 9 meters], the average detection distance increased from 57 to 86 yards [52 to 79 meters] as the season changed from summer to winter, i.e., it increased by 50.8 percent. When the height of the undergrowth was between three and six feet [1 and 2 meters], the average detection distance increased from 61 to 76 yards [56 to 70 meters] from summer to winter, i.e., it increased by 24.6 percent. Finally, when the height of the undergrowth was less than three feet [1 meter], the average detection distance increased from 92 to 95 yards [85 to 87 meters] from summer to winter, i.e., it increased by just 3.2 percent.

These results suggest that the increases in detectability as a consequence of seasonal variation were likely due to reductions in the quantity and/or changes in the color of foliage available for obstructing lines-of-sight between the observer and the target employed in this study. In addition, these results indicate that when foliage in a given forested area is normally obstructive to visual observation or tends to create conditions for low-target contrast, a change in season associated with reductions in this foliage (such as a change from summer to winter) will be accompanied by substantial increments in the average detection distance. On the other hand, when the quantity of foliage is not normally obstructive to visual observation or is not a factor in target contrast, a change in season which affects this foliage will not appreciably affect target detectability in a given area.

Dobbins and his associates at the Tropic Test Center in the Panama Canal Zone have also studied the effects of seasonal variations on detectability in heavily vegetated areas. Their studies were conducted in a tropical evergreen forest located on the Atlantic slope of Panama, and also in a tropical semideciduous forest located on the Pacific slope of Panama. Seasonal variations in these areas are correlated with the amount of rainfall during a given period of time. During the "wet" season the average amount of rainfall is substantially greater than during the "dry" season. One consequence of this is that during the dry season the leaf mass of the vegetation usually withers to some extent and, thus, is less of an obstruction to vision. Therefore, it may be expected that the detectability of personnel targets in tropical forests will be substantially greater in the dry season than in the wet season. This, in fact, was found to be the case for two out of three sites studied in a tropical semideciduous forest.[97] In a later series of studies in this same forest, the detectability of personnel targets was found to vary as expected as a function of wet/dry season variations for only one of three sites studied.[98] The Tropic Test Center researchers suggest that these results were due to the nature of the vegetation at the sites studied. In particular, it was found that the sites which showed changes in detectability as a function of season were characterized by substantial vegetation loss (mainly in terms of leaf drop) as the season changed from wet to dry. On the other hand, sites which did not show substantial improvements in detectability as a function of the change from wet to dry season were characterized by minimal or no vegetation loss as the season changed. These results indicate that a change from wet to dry season will affect visibility in a given area only when the vegetation in that area shows pronounced losses as a function of the seasonal change.

This conclusion is further reflected in the results of another series of studies conducted by Dobbins and his associates on the Atlantic slope of Panama in a tropical evergreen forest.[99] For these studies the severity of the dry season was less than that of the dry season in the semideciduous forest. As a consequence, leaf fall was less in the evergreen forest during the dry season that it was in the semideciduous forest during the dry season. The impact of this reduced severity was that the

---

[97] D. Dobbins, R. Chu, and C. Kindick, *op. cit.*

[98] A. Dubuisson and C. Kindick, *op. cit.*

[99] D. Dobbins, M. Gast, and C. Kindick, *op. cit.*

differences between wet and dry season visibilities were not significantly different for each of three geographically separated areas in the evergreen forest.

Taken together, the Drummond and Lackey study and the Tropic Test Center studies suggest that seasonal variations will be a factor in target acquisition insofar as these variations affect the amount of foliage present in a given geographic area which restricts visibility. If, in a given area, the foliage restricts detection distances and if foliage density changes as a function of seasonal changes, it can be expected that visibilities will increase as the season shifts to one favoring the reduction of foliage. On the other hand, if in a given area the foliage is such that visibilities are not restricted by its presence, then seasonal variations will not likely benefit the acquisition process. Further, if in a given area the foliage restricts visibility, but is not affected by seasonal variations, improvements in detectability as a function of seasonal variations cannot be expected.

Between and within given geographic areas, the vegetative cover may vary in terms of density (number per unit area), height, and type. This will be true for both the primary growth of an area (trees, tall bushes, etc.) and the undergrowth (small bushes, shrubs, grasses, etc.). For example, the primary growth of an area may be dense with many tree branches touching and, thus, provide a continuous canopy over the ground. Alternatively, it may be relatively sparse with few or no branches touching and, thus, provide many openings for direct light to reach the ground. The undergrowth may vary in height from a few inches (e.g., mosses and lichens in a tundra area) to many feet (tall shrubs and grasses). Finally, in a given area a wide variety of trees, shrubs, bushes, and grasses may be found growing in close proximity to each other. Thus, it may be expected that between differentially vegetated areas, detectability will differ as a function of differences in the density, height, and type of prevailing vegetation.

However, variations in these characteristics are not generally independent. That is, variations in density may often be correlated with variations in either height or vegetation type. For example, relatively dense growths of trees are often associated with relatively sparse and comparatively short undergrowth. Alternatively, relatively dispersed growths of trees are generally associated with dense and high undergrowth. Thus, the densities of primary growth and undergrowth in forest areas *tend* to be inversely related. However, as will be seen, the relationship is dependent upon both the type of primary growth (evergreen, deciduous, or mixed) and the height of the primary growth, as well as the type(s) of undergrowth (vines, shrubs, grasses, etc.). While these complex relationships make classification of vegetation difficult, field research has produced some results which may be of value in planning for future acquisition studies.

For example, in a study of 392 stands of vegetation, Drummond and Lackey[100] found that each of the variables discussed above (taken separately) significantly influenced the distance at which a man-sized target could be seen by observers. These stands of vegetation represented a wide variety of primary growth (trees) and undergrowth (bushes, shrubs, and

---

[100] R. Drummond and E. Lackey, *op. cit.*

grasses) which differed considerably in terms of height and density. As a consequence, a classification system was employed which allowed the primary growth and the undergrowth of each stand of vegetation to be placed into one of several sub-categories with respect to density, height, and type of vegetation.

Three levels of vegetative density were investigated: continuous growth, interrupted growth, and growth in patches or clumps. The growth of an area was considered to be continuous if the branches of the trees or undergrowth touched each other. If the branches did not touch, it was considered interrupted. Finally, it was considered to be growing in patches or clumps if open space existed between various groupings of the vegetation. With respect to the last level of density, only three of the stands investigated were classified in this manner. Thus, most of the stands of vegetation were classified as either continuous or interrupted for both the primary growth and the undergrowth.

For stands composed of tall (at least 75 feet [23 meters]) evergreen trees, tall evergreen/deciduous trees, and medium (between 30 and 75 feet [9 and 23 meters]) deciduous trees, the average detection distance was greater when tree density was interrupted than when it was continuous. This result was apparently due to the fact that for the interrupted stands investigated, the undergrowth was relatively short (less than one meter), while for the continuous stands it was relatively tall (greater than one meter). Thus, for the interrupted stands, there were fewer obstructions to vision provided by the undergrowth when compared to that of the continuous stands. As a consequence, it was possible to acquire targets at longer ranges under the interrupted density conditions.

However, for stands composed of medium evergreen trees, low deciduous trees, low (between six and 30 feet [2 and 9 meters]) evergreen trees, and low evergreen/deciduous trees, the average detection distance was greater when the density was continuous than when it was interrupted. For these stands the height of the undergrowth was approximately the same (greater than one meter), but the density of the undergrowth changed as a function of the density of the trees composing the stands. For the continuous stands, the undergrowth was generally open with few branches touching each other. For the interrupted stands, the undergrowth was generally closed with many touching branches. As a consequence, it was possible to acquire targets at longer ranges under the continuous density condition in this case, since the undergrowth tended to be more open and provided fewer obstructions to target acquisition.

Target acquisition in the forest stands studied by Drummond and Lackey was also found to be strongly influenced by height of both the primary growth and the undergrowth. It was found that the average detection distance was directly related to height in primary growths composed of evergreen and mixed evergreen/deciduous trees. In these stands detectability was found to be greatest in the tallest stands and least in the lowest stands. For the deciduous stands studied, it was found that medium height stands (30 to 75 feet [9 to 23 meters]) permitted the greatest average detection distances. In both the tall (greater than 75 feet [23 meters]) and low (six to 30 feet [2 to 9 meters]) stands, detectability was reduced to about the same level due to the presence of visual obstructions (tall undergrowth and vines in the tall stands and dense undergrowth and branches in the low stands). Finally, it was found that height of the undergrowth was negatively related to detectability, i.e., the taller the undergrowth, the less the average detection distance.

Drummond and Lackey also found that the type of vegetation composing a forest had a significant effect on the average detection distance obtained. For tall stands of continuous (upper branches touching) vegetation, it was found that evergreen forests were much more open than deciduous summer forests. As a consequence, detection distances were about three times as great in the evergreen forests (average distance = 71 yards [65 meters]) than in the deciduous forests (average distance = 26 yards [24 meters]). However, for medium forest stands, it was found that there were differences in the average detection distances for the evergreen and deciduous forests only when the primary growth was interrupted (branches did not touch each other). Under interrupted conditions, the average detection distances obtained in the evergreen forests (average distance = 41 yards [38 meters]) was only about half that obtained in the deciduous forests (average distance = 82 yards [75 meters]). When the primary growth was continuous for medium height forests, it was found that the average detection distance was roughly the same (average distance, evergreen forest = 55 yards [50 meters], and average distance, deciduous forest = 62 yards [58 meters]). For stands in which the trees were relatively short, it was found that regardless of the density of the primary growth, visibilities for the evergreen and deciduous forests were also about the same. In addition, it was found for forests in which the vegetation was mixed evergreen and deciduous, that the evergreen vegetation was the dominant factor in limiting the average detection distance. Finally, it was found that the presence of vines (which was very common in deciduous and mixed forests and rarely observed in the evergreen forests) was a highly significant factor influencing target detectability. In particular, it was found that vines tended to reduce the average detection distance by about 36 percent when they were present.

Thus, it is very clear that acquisition performance in forested areas is likely to be greatly influenced by the type, height, and density of vegetation present. In general, then, it can be expected that target acquisition performance will be sharply restricted in areas composed of short deciduous trees with tall, dense underbrush. On the other hand, target acquisition performance will be optimal (all other factors equal) in areas composed of tall evergreen trees with little or short underbrush.

Location. Target location refers to the azimuth of a target relative to an observer's heading. Specifically, azimuth is the horizontal direction of the target expressed as the angular separation between the observer's heading and the target's heading. Usually, field studies of target acquisition systematically vary target location in order to control for the possibility of differential difficulty in detection along different azimuths.

Dobbins and his associates have conducted a number of studies at the US Army Tropic Test Center in the Panama Canal Zone which have systematically investigated the effect of target location on acquisition.[101,102,103,104]

[101] D. Dobbins and M. Gast, *op. cit.*

[102] D. Dobbins, M. Gast, and C. Kindick, *op. cit.*

[103] D. Dobbins and C. Kindick, *op. cit.*

[104] A. Dubuisson and C. Kindick, *op. cit.*

Observers in these studies were given instructions to search for targets in a 180° field. Targets were located within a 120° or 150° sector along either five or ten predetermined azimuths. The results of these investigations indicated that target acquisition was not significantly influenced by target location. In these studies, a minimum of vegetation was distributed along target azimuths. This was done to preclude the establishment of strong location clues for observers.

Anstey, in a review of visibility measurement conducted in forested areas, concluded that whether a particular target azimuth will affect detectability depends upon the density of vegetation along the azimuth.[105] In particular, he found that as the density of vegetation along different azimuths varied, acquisition performance also varied. These findings taken together thus suggest that target location will be a factor in acquisition when lines-of-sight between the target and observer are obscured by either vegetation or some terrain feature.

However, there are at least two other factors to be considered with respect to the effect of target location on ground-to-ground acquisition performance: (a) the observer's search pattern, and (b) the correspondence between a target's physical location and that expected by an observer. Research conducted in an air-to-ground target acquisition situation by Snyder[106] suggests that each of these factors may be important in ground-to-ground target acquisition. For example, Snyder found that observers

---

[105] R. Anstey, *op. cit.*, 1964.

[106] H. Snyder. "Dynamic Visual Search Patterns," in *Visual Search*, Minutes of Symposium Conducted at the Spring Meeting of Committee on Vision (1970), National Research Council, Washington, D.C., 1973.

in air-to-ground situations tend to fixate their eyes on areas in the middle of their visual field. It was concluded that this search pattern was inadequate for detecting targets that fell outside the center of the field of view. These results imply that if the observer's search pattern does not lead to search areas where targets are located, acquisition performance will be lower than if the search pattern does lead him to search locations in which targets are positioned.

Further, Snyder found that observers in an air-to-ground acquisition situation tend to concentrate their search for ground targets on terrain areas in which targets can be logically expected to be present, e.g., roads, clearings. These results suggest that observers tend to have certain predispositions for conducting a search of a given area. This implies that how successful observers will be in acquiring targets in a given acquisition situation will also be a function of the extent to which these search dispositions and actual target locations correspond.

Overall, these findings indicate that the effect of target location on acquisition performance in field situations is dependent on at least three factors: (a) the extent to which the line-of-sight between a target and an observer is masked by either vegetation or some terrain feature, (b) the observer's search pattern, and (c) observer's expectations concerning target location. In particular, it may be expected that target location will be a factor in the acquisition process when few target-to-observer lines-of-sight are available. Location may also be a factor when targets are located in an area infrequently searched by an observer. Finally, location is important when target locations and observer expectations about target location are significantly disparate.

<u>Position of the illumination source</u>. As discussed earlier in this review, in nature, the sun and the moon are the significant sources of illumination. If the time for data collection is sufficiently long during an acquisition study, it will be observed that the elevation of the appropriate illumination source (e.g., the sun or moon) will vary with respect to the observer and the target. In addition, the azimuth of the illumination source may also vary depending on target and observer positions. Both laboratory and field studies have shown that these changes in the position of the illumination source significantly affect the target acquisition process.

Gordon and Lee[107] studied the effects of variations in illuminator azimuth and elevation in a model simulator study conducted in the laboratory. Targets in this investigation were olive drab colored military personnel and vehicular models. The dependent variable in this study was the range at which targets were detected. This study was conducted under two illumination conditions: .02 foot-candles (three-quarter moon illumination) and 2 foot-candles (mortar flare illumination). Detection threshold functions relating the range of the targets at detection to the illuminator azimuths and elevations investigated in the study were separately developed for each illumination condition. These functions were similar for both illumination levels, with the higher illumination level being associated with better acquisition performance. For source azimuths

---

[107] D. Gordon and G. Lee. *Model Simulator Studies - Visibility of Military Targets as Related to Illuminant Position*, University of Michigan, Ann Arbor, March 1959.

varying from 18 degrees through 45, 90 and 135 degrees to 180 degrees, it was found that the detection ranges were longest for the end point azimuths (18 and 180 degrees) and shortest for the middle azimuths (45, 90 and 135 degrees). For source elevations varying from 5 degrees through 45, 90, and 135 degrees to 175 degrees, it was found that the detection ranges were also longest for the end point elevations (5 and 175 degrees) and shortest for the middle elevations (45, 90, and 135 degrees). In particular, the 45 degree elevation produced the shortest detection ranges. These results were interpreted in terms of changes in the target/background brightness contrast that occurred as a function of changes in the azimuth and elevation of the light source. In particular, it was observed that if a target was illuminated directly from the front (18 degree azimuth and 4 degree elevation), it appeared lighter than the background and, thus, had high contrast. As the amount of direct frontlighting decreased due to changes in azimuth or elevation, it was observed that targets became darker and contrast decreased. As the amount of direct backlighting increased, it was observed that targets began to cast distinct shadows which tended to increase their contrast. Finally, as targets were illuminated directly from the rear (180 degree azimuth and 175 degree elevation), target shadows became maximally distinct and contrast was at its highest. Thus, the superiority of acquisition performance for front and rear illuminated targets appeared to be due to high target/background contrasts produced by front and rear lighting of the targets. These results thus suggest that in field situations the position of the source with respect to observer and target positions should be an important factor in the acquisition process. Field investigations of acquisition support this conclusion.

Caviness and Maxey studied the effect of illuminator position on the acquisition of moving personnel targets in an open field during the day.[108] In this investigation only two illuminator positions were studied, a frontlighting position and a backlighting position. Their results indicated that the detectability of relatively low contrast targets (green uniformed soldiers) was significantly influenced by illuminator position, while the detectability of relatively high contrast targets (black uniformed soldiers) was not. Further, it was found that backlit targets were detected at longer ranges and in a shorter amount of time than frontlit targets. These results suggest that backlighting probably facilitated the detection process by increasing the contrast of targets through the casting of shadows toward observers.

Similar results were obtained in a study conducted by the Japanese Infantry School for frontlit and backlit targets under conditions of low ambient illumination.[109] The illuminant source in this investigation was the moon. The moon was either behind, or in front of, the observer. In the former case, targets were backlit, while in the latter case, they were frontlit. For both single personnel and unit-size targets, acquisition occurred at longer ranges under conditions of backlighting.

Thus, these studies clearly show that the position of the source of illumination for a field area can have a profound effect on the acquisition of military targets in that area. However, it appears that the effect of illuminator position is dependent upon the relative contrast of

---

[108] J. Caviness and J. Maxey, *op. cit.*

[109] "Principles of Night Combat," *op. cit.*

the targets being illuminated. For low contrast targets, improvements in detetability may be expected as the position of the light source is varied to produce frontlighting or backlighting. Further, it may be expected that target backlighting will be associated with higher detection levels than target frontlighting. On the other hand, for high contrast targets, it may be expected that variations in illuminator position will be associated with only slight improvements in detectability. This is because improvements in detectability through variations in illuminator position come through substantial increases in target contrast which are difficult to produce when contrast is already at a high level.

Ambient Temperature. The ambient temperature of a given geographic environment is àn obvious and easily measured characteristic. With respect to target acquisition performance, ambient temperature is important as it may affect performance in either a positive or negative way. The temperature of a given geographic area will vary as a function of its altitude, its latitude, the presence or absence of certain terrain features (bodies of water, mountains, vegetation, etc.), time of day, and season of the year. Since military operations are likely to be conducted under almost any temperature condition, it is important to know what effect variations in temperature have on the acquisition process. In addition, due to the presence of military forces in geographic areas that have characteristic high ambient temperatures (e.g., tropic areas such as Panama and Puerto Rico) or very low ambient temperatures (e.g., arctic areas such as Alaska and Iceland), it is important to know if the acquisition process is affected by extreme temperatures and, if so, to what extent.

None of the studies reviewed for this report investigated the effect of temperature variations on the acquisition process under field conditions. No studies were located which investigated the effects of extreme heat or extreme cold on the acquisition process. Most studies reviewed were conducted in temperate environments. In these studies no mention was made of the effects of temperature on target acquisition. Several of the studies reviewed were conducted under tropic temperature conditions, but in these investigations no mention was made of temperature effects on target acquisition performance. Finally, no target acquisition field studies were located which had been conducted under arctic temperature conditions.

However, Sells and his associates have reviewed the literature concerning the effects of heat[110] and cold[111] on human performance. Most of the research they reviewed was conducted in laboratory settings. Several interesting findings emerged from their work. With respect to the effects of heat (temperatures above about 70°F) on human performance, it was found that performance variations depended upon the intensity of the heat, the duration of exposure to the heat, the type of task undertaken, characteristics of the individuals performing the tasks under heat conditions, and the presence or absence of other stressing conditions.

Some of their specific findings with respect to heat were:

---

[110] M. Duke, N. Findikyan, J. Anderson, and S. Sells. *Stress Reviews: Thermal Stress-Heat,* Technical Report No. 11, Institute of Behavioral Research, Texas Christian University, Fort Worth, May 1967.

[111] M. Duke, N. Findikyan, and S. Sells. *Stress Reviews: Thermal Stress-Cold,* Technical Report No. 8, Institute of Behavioral Research, Texas Christian University, Fort Worth, May 1967.

(1) In general, the greater the intensity of heat, the greater the decrement in performance.

(2) In general, tolerance time decreased as the intensity of heat increased and performance exhibited greater decrements with longer exposure times.

(3) In general, there was a greater consistency for physical tasks to show impairments under extreme heat conditions than mental tasks. However, vigilance tasks, which are very similar to acquisition tasks, appeared to show reliable decrements as temperature increased.

(4) As the task load (increased number of tasks) was increased, the amount of decrement as a function of increments in the amount of heat also increased.

(5) Acclimatized subjects were found to perform better than unacclimatized subjects.

(6) Unskilled or inexperienced subjects showed greater performance decrements than skilled or experienced subjects.

(7) Highly motivated subjects were found to resist the effects of heat on performance better than less motivated subjects.

(8) Such factors as high humidity, low air movement, and fatigue when combined with high temperatures accentuated the effects of heat.

With respect to the effects of cold (temperatures below about 70°F) on human performance, Duke, Findikyan and Sells found that the major effect of cold was to produce performance decrements in tasks for which fine manual dexterity was important for successful task completion. Few studies were found by these researchers involving visual tasks. However, the evidence from these few studies indicate that performance in visual tasks with no component of manual dexterity did not decline under conditions of cold. Kobrick, however, has reported performance decrements for visual acuity and depth judgment tasks as a function of cold temperatures.[112]

---

[112] J. Kobrick. "Environmental Factors Affecting Visual Perception," in *US Army Human Factors Research and Development Conference Report*, Sixteenth Annual Conference, Fort Bliss, Texas, October 1970, pp 165-178.

Thus, the research on the effects of temperature on human performance indicates that under either temperature extreme, deterioration in human performance may occur. With respect to heat conditions, it may be that to the extent the acquisition task is similar to vigilance tasks, some performance decrements will likely occur in field situations. This effect will be marked if extended operations under temperatures exceeding approximately 90°F[113] are contemplated. Further, it may be expected that unskilled observers or unmotivated observers will show substantial decrements in performance relative to skilled or experienced observers. With respect to cold conditions, losses in visual acuity or reduced depth perception may occur. Visual acuity or depth perception will, in turn, almost certainly affect target acquisition performance. Since US military operations are likely to be conducted in the future under almost any environmental condition, it would appear that the effect of temperature on the acquisition process would be an appropriate area for research. From such research, more definite statements with respect to the effects of heat and cold variations and extremes on target acquisition performance could be made.

Task Characteristics

Conceptually, all target acquisition studies involve a minimum of three basic components: a target, a context in which the target appears, and an observer. The manner in which these components are related depends on the rules and procedures governing the conduct of the task. It is the purpose of this section of the review to consider and discuss the effects of variations in task rules and procedures on the acquisition process.

---

[113] J. Duke, N. Findikyan, J. Anderson, and S. Sells, *op. cit.*, p. 29.

Observer movement. In some military situations it can be expected that the observer will move as he attempts to acquire a target. In other situations the observer will have to remain stationary as he attempts his task. Field research has found that observer movement can affect acquisition performance.

For example, Caviness and Maxey[114] studied the effect of observer movement on the detection of advancing (walking) personnel targets in an open field area. In this investigation, both moving and stationary observers searched for single personnel targets dressed in olive drab colored uniforms. The targets advanced from the end of a long (1200 meters) field covered in tall grasses. They found that the moving observers acquired targets sooner and at longer ranges (average detection time = 36.5 seconds and average detection range = 1053.3 meters) than did the stationary observers (average detection time = 76.5 seconds and average detection range = 1004.5 meters). Statistically, however, only detection times were different for the two conditions of observer movement.

However, Anstey[115] reviewed studies of target detectability in various forested areas and noted that observer movement provided only a slight advantage in the detection of stationary targets in a mid-latitude mixed forest. In this investigation, a stationary observer detected a stationary personnel target dressed in an OG 107 uniform at an average distance of 70 feet [21 meters]. However, in the same area, an observer who moved away from the stationary target detected the target at an average distance of 77 feet [24 meters2. Thus, for this experimental situation, observer movement did not improve target acquisition performance.

---

[114] J. Caviness and J. Maxey, *op. cit.*

[115] R. Anstey, *op. cit.*, 1964.

Taken together, these results indicate that observer movement may be a significant factor in the acquisition process, but only when the target is also moving. This is probably due to the fact that moving observers generate qualities of movement perspective (e.g., motion parallax) that tend to accentuate the slight lateral displacements of moving targets when they advance toward or move away from an observer. However, it should be pointed out that these results were obtained in two separate studies conducted in two distinctly different terrain areas (in one study, an open field; in the other, a forested area). As a consequence, it would be appropriate to investigate these conclusions under the same environmental conditions to determine their overall validity and generality.

Size of search area. It has been found that variations in the size of the area to be searched during an acquisition task are related to the quality of acquisition performance.

For example, in a laboratory detection situation, Brody, Corbin, and Volkman[116] investigated the effect of target brightness and search area size on the acquisition of small circular targets. They found that both the target brightness and the size of the search area significantly affected the percentage of the targets detected. For very bright targets (13.5 foot-lamberts), acquisition performance was almost perfect over the entire range of search areas investigated (32, 64, 96, 128, and 158 degree search areas). However, for very dim targets (0.58 foot-lamberts), the percentage of targets detected decreased as the size of the search area was increased over the range from 32 to 158 degrees.

---

[116] H. Brody, H. Corbin, and J. Volkman. "Stimulus Relations and Methods of Visual Search," in A. Morris and E. Horne (eds.), *Visual Search Techniques,* Publication 712, National Academy of Science, Washington, D.C., 1960.

Similar results were obtained by Johnston[117] with respect to the effects of search area size on target acquisition performance. In this laboratory study, observers were required to locate target objects embedded in displays of similar target-like objects. Three search area sizes were investigated: 11.25, 22.50, and 45.00 degrees. For all search areas, the size of the target and target-like objects and object density (number of objects per unit area) were held constant. As a consequence, the between-object distances were kept relatively equal and the overall display appeared relatively uniform to the observers. It was found that as the size of the search area increased, the amount of time required to locate the embedded target object also increased in a linear manner. However, it should be mentioned that since object density was kept constant across the three search areas, search area size was partially confounded with the total number of objects to be searched. As a consequence, the above result may have also been partially due to the increased number of objects that had to be searched in order to locate the target object.

The effect of variations in search area size on detection performance has also been studied by Krendel and Wodinsky[118] in a series of laboratory investigations. The experimental situation in these studies required observers to find a small visual target in a broad unstructured surround (a white screen 84 inches [2.1 meters] wide by 91.5 inches [2.3 meters]). The results of these studies showed that as the size of the search area

---

[117] D. Johnston. *Search Performance as a Function of Peripheral Acuity*, Research Report D6-57100, Boeing Company, June 1975.

[118] E. Krendel and J. Wodinsky. "Visual Search in Unstructured Fields," in A. Morris and E. Horne (eds.), *Visual Search Techniques*, Publication 712, National Academy of Science, Washington, D.C., 1960.

was increased from 6.8 degrees through 18 and 32 degrees to 43 degrees, the percentage of targets detected decreased, while the amount of time required for detecting the target increased.

Finally, in a series of studies conducted by Banks and his associates at the Hunter-Liggett Military Reservation,[119] the effect of variations in search area size on detection performance (percent detections) using passive night vision devices was assessed under field conditions. In the first of these studies, Banks, et al., varied the search area size under three illumination conditions: starlight, half-moon, and full moon illumination. This effect was seen to hold over all devices tested. At the starlight level of illumination, a decrease in the size of the search area from 75 degrees to either 35 or 25 degrees resulted in only small or no improvements in acquisition performance. These results were for targets exposed for 120 seconds. With shorter exposure times for targets (from 15 seconds to 90 seconds in 15-second increments), the improvement that resulted from a decrease in the search area was substantial under both the starlight and full-moon illumination conditions. Similar improvements in performance were obtained in the second study of this series as the size of the search area was reduced from 75 to 35 degrees.[120]

The results of both the laboratory and field research indicate that as the search area is reduced, generally the percentage of targets detected improves with reductions in the time required to detect targets. In addition, these results indicate that the effects of reductions in search

---

[119] J. Banks, et al., *op. cit.*, 1971.

[120] J. Banks, J. Sternberg, B. Cohen, and C. Debow, *op. cit.*

area size appear to be dependent upon the brightness of the target, the ambient illumination level of the surround and target exposure time. Finally, these results imply that it is exceedingly important to control the amount of area searched during an acquisition study or in a combat situation, since the amount of area searched will tend to affect the percentage of targets detected and/or the time required for detection.

Practice effects. While an observer may bring specific skills and experience to an acquisition situation which can assist in the successful completion of the acquisition task, it is likely that with repeated practice an observer's performance will also show some improvement. This could be due to the operation of several factors. With practice the observer may learn to expect targets to appear only in certain areas and, as a consequence, he will attend to just those areas during his search. Additionally, with practice, he may change his search strategy until he hits on a strategy that results in a greater number of successful acquisitions. Finally, with practice, his reaction time may show improvements which are reflected in shorter acquisition times and longer acquisition ranges. Only a limited number of field acquisition studies have focused on practice effects in target acquisition. These studies have failed to yield evidence consistent for the existence of practice effects. For example, Caviness and Maxey[121] (in several similar acquisition studies conducted in an open terrain area during the daytime, using olive drab uniformed personnel targets) found that the average detection time decreased and the average detection range increased with practice. Gordon and Lee[122] found

---

[121] J. Caviness and J. Maxey, *op. cit.*

[122] D. Gordon and G. Lee, *op. cit.*

similiar improvements in detection performance as a function of practice. These workers used a laboratory simulation of a ground acquisition situation and conducted their investigation under low ambient light conditions.

However, other studies on the acquisition process report no improvement in acquisition performance as a function of practice. Dobbins and his associates[123,124] at the Tropic Test Center in the Panama Canal Zone consistently failed to find any practice effects for acquisition performance. In these studies observers attempted to detect personnel targets in dense tropical forest situations under conditions of low to moderate illumination.

The basis for these contradictory findings is not immediately clear. At this point, without further research, it can only be concluded that practice effects may occur. As a consequence, the possibility of such effects must be taken into account during the design of investigations of the acquisition process.

Search method. In the vast majority of field acquisition situations, it is usually necessary for the observer to spend some period of time inspecting the visual environment for evidence of the target's presence. This inspection process is referred to as *search*. Search may be conducted in an uncontrolled or unstructured fashion or it may be conducted by some specified procedure or plan. Field research has found that the method of search employed for finding target objects can significantly affect the quality of acquisition performance, both in terms of time and correctness.

---

[123] D. Dobbins, R. Chu, and C. Kindick, *op. cit.*

[124] A. Dubuisson and C. Kindick, *op. cit.*

Thomas and Caro[125] studied the effect of four different methods of visual search on the acquisition of stationary ground targets by military observers in a low flying aircraft. In this study the observers received training in a classroom situation in one of the four visual search procedures prior to the measurement of their acquisition performance. The four procedures were: (1) the *Forward Fixed Method* -- in which the observer looked forward at a 45 degree angle to the line of flight and downward to the terrain with his head in a fixed position; (2) the *Forward Movement Method* -- in which the observer initially looked forward at a 45 degree angle to the line of flight, then swept his gaze back to the rear of the aircraft, and then repeated the procedure; (3) the *Side Fixed Method* -- in which the observer looked at the terrain along a line-of-sight perpendicular to the line of flight of the aircraft with his head held in a fixed position; and (4) the *Side Movement Method* -- in which the observer looked back and forth along a line-of-sight perpendicular to the line of flight of the aircraft. Subsequent to the classroom training, the observers completed a field test during daylight hours designed to evaluate the relative effectiveness of each of the visual search methods. The results of the field test indicated that the *Side Movement Method* produced the highest percentage of correct identifications. The two forward methods (*Forward Movement* and *Forward Fixed* methods) produced the next best acquisition performance. Finally, the *Side Fixed Method* was associated with the lowest level of acquisition performance. Thus, in this case, the type

---

125 F. Thomas and P. Caro. *Training Research on Low Altitude Visual Aerial Observation: A Description of Five Field Experiments*, HumRRO Research Memorandum, Human Resources Research Organization, Alexandria, Virginia, July 1962.

of search method employed by observers during testing had a significant effect on the quality of acquisition performance obtained during the test.

Banks and his associates[126] also studied the effects of varying search methods on acquisition performance. In this investigation, military observers using various passive night vision devices received training in specific search techniques deisgned to provide systematic and comprehensive coverage of a search area. These were: (1) the *Discrete/Overlap Search Method* -- in which the observer searched an area in discrete steps such that there was overlap between successively searched areas; (2) the *Discrete/No-Overlap Search Method* -- in which the observer searched an area in discrete steps such that there was no overlap between successively searched areas; and (3) the *Continuous Search Method* -- in which the observer searched an area in a continuous movement at a variable rate, stopping only to examine an object of interest. Following this training, the acquisition performance of the observers who received the special search training was measured and compared to that of observers who had received the standard search training. This latter training was designed to familiarize observers with the acquisition situation and the basic acquisition task. It consisted of 45 minutes of free search practice in finding targets. Evaluation of the various types of training was conducted under two levels of low ambient illumination (starlight and full-moon illumination) with targets at near, mid, and far distances. Overall, the special training groups did not differ significantly from each other in either the percentage of targets detected or the time required for target detection. However, they demonstrated higher quality

[126] J. Banks, J. Sternberg, B. Cohen, and C. Debow, *op. cit.*

acquisition performance than the standard training group, both in terms of improved percent detections and lowered detection time. The improvement demonstrated by the special training group relative to the standard training group was less under full-moon than under starlight illumination conditions. Further, the relative improvement demonstrated by the special training group was greater at the far target ranges than at the near or mid target ranges. These results suggest that special training designed to teach observers to systematically and comprehensively cover a given search area may prove superior to training designed only to familiarize observers with the acquisition situation and the basic acquisition task.

On the other hand, several studies have found that special search strategies do not necessarily lead to improved acquisition performance. Gottsdanker[127] had civilian observers find target objects of four different types that appeared under conditions of embeddedness or competition (high similarity between target and non-target objects). Observers searched alternately, employing two search strategies. One strategy was "free search"; that is, they could search in any manner they chose. The alternate strategy was an item-by-item examination of all the objects in the display. For both acquisition situations (embeddedness and competition) the average detection time was lower for the free search than for the structured search strategy.

---

[127] R. Gottsdanker. "The Relation Between the Nature of the Search Situation and the Effectiveness of Alternative Strategies of Sectors," in A. Morris and E. Horne (eds.), *Visual Search Techniques*, Publication 712, National Academy of Science, Washington, D.C., 1960.

Baldwin[128] also found that structured search does not necessarily lead to improved acquisition performance. In a series of four laboratory experiments, military observers employed either free search or one of two structured search strategies to acquire near-threshold spherical targets presented against an open, bright background. Collectively, the results of the investigations indicated that, when compared to the free search strategy, the structured search strategies did not produce shorter acquisition times.

Overall, these results clearly indicate that, in certain circumstances, the type of visual search strategy employed by an observer can affect the quality of his acquisition performance. Thus, in studies of the acquisition process, data should be recorded which reflect the search strategy employed by the observer. Such a procedure will account and control for differences in acquisition performance due to search strategy variations. Further, if a particular search strategy has been tested and validated with respect to its effectiveness, then it may be appropriate to require observers to use this strategy to improve their performance.

In addition, these results indicate that whether or not a particular search strategy will be superior to a free strategy depends upon conditions which are not totally clear at this particular time. The results of the studies conducted by Banks and his associates suggest that the effectiveness of specific search strategies can be dependent upon both target and environmental variables. This would imply that the failure to find a

---

[128] R. Baldwin. *Attempts to Improve Visual Detection Through the Use of Search Patterns and Optical Aids*, HumRRO Technical Report 73-3, Human Resources Research Organization, Alexandria, Virginia, February 1973.

relationship between variations in search strategy and acquisition performance in some instances may be due to operation of certain target and/or environmental factors. This is an area that should receive attention in future target acquisition research.

Duration of observation. Experimental studies of the acquisition process are usually designed so that individual observations require relatively small amounts of time, e.g., seconds or minutes. In some studies, observers make only a few observations in an experimental session. Generally, these observations are completed successively with either short or only moderately long intertrial intervals. In other cases, observations are grouped into blocks of trials and completed over a number of experimental sessions. Under either of these conditions, however, the total amount of time actually spent in the acquisition of targets is usually not very long, e.g., at most one or two hours.

There are several reasons for limiting time requirements in target acquisition situations. First, due to either personal or job commitments, observers are usually available for use in an acquisition study for only limited periods of time. Thus, it is to the experimenter's advantage to design his acquisition situations so that the most can be obtained from an observer in a minimum amount of time. Second, for reasons of good experimental design, it is often necessary to keep the number of observations made by a given observer to a minimum. While this procedure avoids such problems as the development of interdependencies among observations and minimizes practice effects, it also acts to minimize the amount of time actually spent acquiring targets. Finally, the probability of performance decrements due to fatigue or boredom is greatly reduced by designing studies to minimize observer experimental time in a given data collection session.

However, in a realistic combat situation, it cannot be expected that the acquisition task will be conducted for only short periods of time. In particular, it is anticipated that future military operations will be conducted on a continuous basis during both day and night hours. Thus, it may be expected that acquisition tasks in these situations may be performed for relatively long periods of time on a continuous basis. As a consequence, it is important to determine if prolonged observation is associated with significant decrements in acquisition performance.

McGrath, Harabedian, and Buckner[129] have reviewed the literature on the effects of task duration on the performance of vigilance tasks. Vigilance tasks are typically defined by the following characteristics: (1) the observer is required to perceive and report the presence or absence of some specified and relatively infrequent change in his environment, (2) the change (called the signal) may be addition or removal of a discrete stimulus or it may be a momentary change in a continuously presented stimulus, (3) the intensity of the change is usually suprathreshold, but not so intense as to induce the involuntary attention of the observer, (4) the time of signal presentation is usually unpredictable by the observer, (5) the task generally is completed over a relatively long period of time (usually not less than a half hour, but for not more than about eight to ten hours), and (6) usually more than just a single momentary judgment is required from the observer during the course of task completion.

---

[129] J. McGrath, A. Harabedian, and D. Buckner. *Review and Critique of the Literature on Vigilance Performance*, Technical Report 206-1, Human Factors Research, Inc., Goleta, California, December 1959.

These researchers report that generally detection performance in vigilance situations declines with increased time during an experimental session. Experimental work conducted in the late 1940s and early 1950s indicated that performance decrements usually occur within the first 10 to 30 minutes of task performance. After this initial decrement, performance tends to stabilize at a reduced level of signal detection. Later experiments, however, have indicated that this decrement in performance appears to reach a maximum for most observers after about 15 minutes of task performance. Further, they report there is some evidence that slight performance improvements occur during the first few minutes of task performance. Finally, they found that, for the same observers, vigilance performance was poorer during an afternoon vigilance session than during a morning session.

The experimental evidence reviewed by these researchers indicated a well-defined relationship between time on task and vigilance performance for a single or interrupted (session included scheduled breaks) vigilance session. However, the course of vigilance performance from day to day was not readily apparent from the experimental literature. In some research, it was found that from the first to the second or third days, vigilance performance showed improvements and then on following days a tendency toward stabilization. Lindsley, et al.,[130] investigated vigilance performance over 17 days and found that task performance was poorer on the later days than on the first few days.

---

[130] D. Lindsley, et al. *Radar Operator "Fatigue": The Effects of Length and Repetition of Operating Periods on Efficiency of Performance*, Report No. SRO 3334, Office of Scientific Research and Development, 1944.

Thus, this information clearly suggests that a vigilance decrement may be expected in the first 10 to 30 minutes of a session. In addition, between-session decrements may occur, but it is not clear how many consecutive daily sessions must be completed before such decrements occur. From these findings it may be expected then, that to the extent a target acquisition situation can be characterized as a vigilance situation, performance decrements will occur as time on the task increases. Thus, for example, it might be expected in a field situation where an observer had to monitor a relatively small area of ground for targets appearing infrequently, performance decrements in acquisition would occur with increased time on the job. However, until such research is conducted, the effect of continuous observation on a vigilance-like target acquisition task cannot be precisely determined.

Deese[131] has reviewed some of the early literature on the effects of prolonged work on the performance of active visual tasks. Active tasks were defined as those which involved the continuous use of the oculomotor system and required more or less continuous mental operation. He concluded that relatively long periods of work at active tasks were associated with no or little deterioration in the capacity for continued visual work. However, a decrement could be expected if the situation was complicated by loss of sleep, anoxemia (low level of oxygen in the blood), or the presence of drug effects. In addition, he found that continuous work at these tasks was often associated with reports of depression, headaches, feelings of tiredness, and irritability. Further, there was some evidence of increased somatic muscle tension with prolonged work.

---

[131] J. Deese. *Changes in Visual Performance After Visual Work*, Johns Hopkins University, Baltimore, Maryland, April 1957.

Deese's conclusions with respect to the course of prolonged performance of active visual tasks suggest that, to the extent a visual acquisition task can be characterized as an active task, it can be expected that performance decrements will not occur or will be minimal as a function of increased observation time. This assumes that the acquisition situation is not complicated by losses in sleep, anoxemia, or drug effects. Recent research by Drucker, Cannon, and Ware[132] tends to support these conclusions. These workers studied the acquisition performance of military observers in a laboratory situation designed to assess the course of prolonged performance on an acquisition task. The acquisition task in this study required observers to detect flashes of light presented at an average rate of six flashes per minute. The flashes appeared at irregular intervals in randomly located areas on a large screen (divided into four quadrants) located 23 feet [seven meters] from the observers. When a signal was detected the observer pressed one of four response buttons located on a panel directly in front of him. The response buttons corresponded to the quadrants of the screen. The observer was required to press the button that corresponded to the quadrant in which the signal occurred. Thus, while this task was basically a vigilance task with a moderate to high signal rate, in practice it was an active task in that it required observers to continuously use their eyes and be mentally alert.

The observers worked under a specified schedule over a period of 48 hours. Some observers worked a total of 36 hours spaced over 24 work periods. Work periods were 1.5 hours long and were followed by 15-minute

---

[132]E. Drucker, L. Cannon, and J. Ware. *The Effects of Sleep Deprivation on Performance Over a 48-Hour Period*, HumRRO Technical Report 69-8, Human Resources Research Organization, Alexandria, Virginia, May 1969.

rest breaks. Eight one-hour rest breaks were allowed during the work schedule. Other observers worked for 27 hours spaced over 18 work periods. These observers were allowed two five-hour sleep periods in addition to the standard 15-minute rest breaks that followed work periods and the eight one-hour rest periods. Thus, these procedures defined two basic work groups: the no-sleep group and the sleep group.

For the no-sleep group, task performance varied with the time of day, with significant decrements occurring during the evening hours followed by some (though not complete) recovery during daytime hours. In addition, the no-sleep group showed much greater performance decrements during the evening hours of the second night when compared to those of the first night. The sleep group, on the other hand, tended to show no performance decrements from the first day of work to the second day of work. However, the sleep group did not work during the evening hours -- the time when decrements might have been expected. In comparing the two groups' performance during daytime (normal waking) hours, no significant differences were found, although the sleep group did tend to perform at a somewhat higher level. These results clearly show that acquisition performance was affected by extended activity for only those observers who received no sleep and then just during the period when they normally slept.

Ainsworth and Bishop[133] have also studied the effects of extended operations on the acquisition performance of observers. In this investigation observers either worked continuously for 48 hours without sleep or for 48 hours with 24-hour rest periods between each 12 hours of work. Two

[133] L. Ainsworth and H. Bishop. *The Effects of a 48-Hour Period of Sustained Field Activity on Tank Crew Performance*, HumRRO Technical Report 71-16, Human Resources Research Organization, Alexandria, Virginia, July 1971.

types of acquisition situations were studied: a "passive task" and a "moving task." In the passive task situation observers acquired tanks, trucks, and groups of troops located at ranges from 220 to 1010 meters at various azimuths. This task was performed only during daylight hours.

In the moving task situation tank-mounted observers detected teams of personnel firing a crew-served machinegun while moving past the machinegun's position. This task was completed both under conditions of night and daytime illumination.

In the passive task situation the observers who rested (24 hours) between test periods generally detected more targets in shorter periods of time than the observers who worked continuously. In addition, there was a tendency for both groups of observers to improve in their performance with practice. In the moving acquisition task situation over successive 12-hour test periods, the observers who were allowed rest showed successive improvements in performance through the third 12-hour test period and a slight drop from the third to the fourth 12-hour test period. The performance of observers who received no interpolated rest declined from the first to the second 12-hour test period followed by a general improvement in performance with each successive test period. Overall, the performance of the observers who rested was superior to the performance of those who did not rest. Collectively, these results indicate that the efficiency of the observers who worked continuously was reduced compared to the performance of those receiving interpolated rest over the 48-hour test period.

Banks, Sternberg, Farrell, Debow, and Dalhamer studied the effect of prolonged activity on the performance of an acquisition task using a

Starlight Scope under starlight and full-moon illumination conditions.[134] Performance was measured in terms of the percentage of targets detected and the time required for detection. The observers' acquisition performance was measured twice in this investigation: after 15 hours of activity (which included two hours of training in the use of the Starlight Scope) and 24 hours after the first testing. For both measures of acquisition performance, no performance decrement was observed, even though prior to the second testing the observers had worked for 39 hours continuously with only occasional naps.

Similar results were obtained by Sternberg and Banks.[135] They studied the performance of an acquisition task using three night vision devices under conditions of low ambient illumination for a relatively short period of continuous observation (5.5 hours). In particular, the performance of observers using either the Night Observation Device, the Starlight Scope, or the MINI Crew-Served Weapon Sight did not decline in the percent number of targets detected or the time required for detection over the 5.5 hour observation period for comparisons among the first, middle, and end blocks of trials.

Collectively, the results of these investigations indicate that whether performance decrements will occur in a target acquisition situation depends on the nature of the situation. For target acquisitions requiring vigilance, performance decrements within a session can be expected to occur early (within the first 10 to 30 minutes). However, after the initial

---

[134] J. Banks, J. Sternberg, J. Farrell, C. Debow, and W. Dalhamer. *Effects of Continuous Military Operations on Selected Military Tasks*, Technical Research Report 1155, US Army Behavior and Systems Research Laboratory, Arlington, Virginia, December 1970.

[135] J. Sternberg and J. Banks, *op. cit.*

decrement, performance can be expected to stabilize at a reduced level of detection. Further, for repeated performances in this type of situation, performance decrements may occur from one session to the next.

However, when the target acquisition situation requires active visual performance (one in which the oculomotor system is used without interruption and continued mental alertness is necessary for decision making), the experimental evidence indicates that performance decrements will occur only when the situation is complicated by physiologically debilitating events (loss of sleep, drugs, anoxemia). However, for example, when the effects of these events are allowed to dissipate (e.g., rest is allowed), performance decrements are not likely or will only be minimal. Thus, the results of the studies reviewed in this section of the report clearly indicate (a) that duration of observation is an important factor in the acquisition process, but that (b) the effect of this variable is highly dependent on the parameters defining the situation at the time of observation.

Observer Variables

As discussed earlier in this report, most research into the acquisition process has been concerned with the effects of target, environmental, and task parameters on acquisition performance. Usually, in studies of the acquisition process, an attempt is made to minimize or hold constant the effects of observer differences on the process. To this end, observers are selected to minimize individual differences and instructions are employed to standardize observer behavior. Hence, there is very little data on the effect of observer variables on acquisition performance. While there are good practical and experimental reasons for neglecting the study of observer differences, nevertheless, a complete understanding of the acquisition process is not possible without consideration of the "human element." Thus, it is the purpose of this section of the review to consider observer differences as they related to the acquisition process and to assess the impact of these differences on this process.

Visual Acuity

Target acquisition is basically a visual skill whose successful performance is dependent to a large extent upon the size of target objects and the ranges at which these objects appear. Both size and range are related to each other by visual angle. This relationship is given by the equation:

$$\text{Tangent } \left(\frac{VA}{2}\right) = \frac{e}{2R}$$

where VA is the visual angle, e is the measure of size, and R is the measure of range.[136] For small angles (measured in radians), i.e., for angles for which the tangent of the angle is approximately equal to the angle itself ($\tan VA = VA$), this relationship simplies to $VA = e/R$.

One characteristic of the human eye is its ability to resolve fine detail. This ability is often measured in terms of the minimum visual angle that can be resolved by the eye under certain standard conditions. This resolution ability is referred to as the visual acuity of the eye.[137] For clinical and screening purposes, acuity is often measured by having subjects read characters off of standardized wall charts composed of rows

---

136 C. Graham. "Visual Space Perception," in C. Graham (ed.), *Vision and Visual Perception*, New York: John Wiley, 1965.

137 J. Wulfeck, et al., *op. cit.*

of letters or symbols subtending various visual angles. Generally, these charts are designed such that the visual characters on descending rows come to subtend smaller and smaller visual angles. As a consequence, the more descending rows that can be accurately read, the better visual acuity is.[138] Differences in visual acuity will most certainly be associated with corresponding differences in acquisition performance. Specifically, it may be expected that observers with "good" visual acuity will perform at higher levels, especially on an acquisition task involving the detection of relatively distant and/or small targets than observers with "poor" visual acuity.

Baldwin[139] investigated this possibility in a series of laboratory studies involving the acquisition of small black spherical targets presented against a brightly lighted open background. In these studies observers completed the acquisition task under two sets of search conditions: free search and structured search. Acquisition performance was measured in terms of time required to find the target. The far visual acuity of the observers (measured in terms of the smallest visual angle that could be detected) was determined using the Armed Forces Vision Tester. The measured visual acuities ranged from 20/20 to 20/13. Correlations between acquisition performance (the time required for detection) and the measured visual acuity of the observers were found to be significant in most cases. These correlations ranged from .39 to .65 and averaged .50 Further, the magnitude and significance of the obtained correlations did not appear to be related to the method of search employed by the

---

[138] J. Tiffen and E. McCormick. *Industrial Psychology*, Englewood Cliffs, New Jersey: Prentice-Hall, 1965.

[139] R. Baldwin, *op. cit.*, 1973.

observers during the conduct of the acquisition task. Thus, these results suggest that measured visual acuity is likely to be a significant predictor of target acquisition performance in field situations.

Similar results were obtained by Whitehurst[140] in a laboratory simulation designed to evaluate the detectability of variously camouflaged combat vehicles. In this investigation, civilian observers acquired scale models of Armored Personnel Carriers (APCs) camouflaged using several different colors (green, brown, tan, and black) and camouflage patterns. All targets were placed on a terrain model that consisted of green ground cover with assorted trees, sand, and rock. Depending on target location, the APCs varied in size from 34 to 42 minutes of arc as measured from the observer's eyes. Three groups of observers searched the terrain model for the targets. Observers in the first two groups each had an opportunity to acquire 33 targets, while the observers in the third group had an opportunity to acquire only 13 targets. Acquisition performance for each trial was measured in terms of the time required to detect a target. In addition, prior to the target acquisition trials, the far visual acuity of each observer was measured using the Armed Forces Vision Tester. The obtained acuities ranged from 20/20 to 20/12. Correlations between the mean time for detection and far visual acuity (as measured by the percentage of the letters presented in the vision tester that were correctly identified) were -.43, -.61, and -.64. The two latter correlations were significant at an acceptable level of significance ($p<.01$), while the

---

[140] H. Whitehurst. *The Effects of Pattern and Color on the Visual Detection of Camouflaged Vehicles*, NWC TP 5746, Naval Weapons Center, China Lake, California, March 1975.

first correlation was not. Thus, in this case, the results also suggest that visual acuity should be a significant predictor of field acquisition performance.

In a later study conducted by Whitehurst,[141] similar results were obtained with respect to the effect of visual acuity on target acquisition performance. In this investigation, civilian observers searched for both a camouflaged and an olive drab colored APC located at various locations on a terrain model under two lighting conditions (dawn and bright sky light). The average luminance of the terrain model under simulated dawn lighting was 2.0 foot-lamberts, while it was 9.5 foot-lamberts under the bright sky conditions. The visual acuities of the observers were measured using the Armed Forces Vision Tester and were scored as in the previous Whitehurst study. The obtained visual acuities ranged from 20/17 to 20/12. The average time required to find the targets over all combinations of target and lighting conditions was determined for each observer. A significant correlation of -.69 ($p<.01$) was obtained between these times and the visual acuity scores of the observers. Thus, also in this situation, visual acuity was a significant facto in the target acquisition process.

Whittenburg and Collins[142] also found that target acquisition performance was significantly related to measured visual acuity. In this investigation, several groups of observers searched for a variety of

---

[141] H. Whitehurst. *Effect of Camouflage Paint Pattern on the Surface-to-Suface Detection of Vehicles*, NWC TR 5772, Naval Weapons Center, China Lake, California, June 1975.

[142] J. Whittenburg and B. Collins, *op. cit.*

military targets (M48 tank, towed 155mm howitzer, 1/4-ton jeep, and a camouflage net) located either in an open field or next to a treeline. Observers searched for the targets from two observation points. The first point (near to the targets) was located such that the target-to-observer range varied from 88 to 880 meters, while the second point (far from the targets) was located such that the target-to-observer varied from 1055 to 2952 meters. For each observer, a detection score was computed that was based on the number of targets detected and the level of description used by an observer to define acquired targets. These scores were then correlated with the observer's far visual acuity (measured prior to the study in terms of the number of test items correctly completed on the Armed Forces Vision Tester). The obtained acuities ranged from 20/40 to 20/17. For all targets (acquired from both the near and far viewing positions), the correlation between performance and acuity was .224 ($df = 70$, $p<.05$), which was not significant. However, when detection scores reflecting the observer's viewing position were computed and correlated with the visual acuity scores, it was found that the correlation for the detection scores for the near position ($r = .238$, $df = 70$) was significant ($p<.05$). On the other hand, the correlation for the detection scores for the far position ($r = .149$, $df = 70$) was not significant ($p<.05$). These results thus indicate for a field acquisition situation that visual acuity is likely to be an important factor in the acquisition process only for targets located at relatively close ranges, i.e., from about 88 to 880 meters.

Overall, these results indicate that visual acuity is indeed an important factor in the target acquisition process. In general, the results demonstrate that observers with "good" visual acuity can be expected to acquire more targets sooner than observers with "poor" visual acuity. However, the magnitude of the correlations obtained in the studies reviewed suggest that the visual acuity-acquisition performance relationship is far from perfect. In addition, these results suggest that military personnel who wear corrective lens might experience reduced ability to acquire targets in combat situations if their lens were broken or lost. Rapid replacement is unlikely in a combat zone. As a consequence, in future studies of the acquisition process, it might be appropriate to assess the acquisition ability of observers who normally wear corrective lens, both with and without these lens. Such a strategy would allow assessment of the effect of acquisition performance of missing corrective lens.

Color Vision

Collins and Whittenburg have reviewed the literature concerning the effect of variations in observer color vision on target acquisition performance.[143] They report that since World War II the hypothesis that color-deficient individuals can detect camouflaged targets at a higher rate than color-normal individuals has been quite persistent. However, they found that only one relevant empirically-based investigation of this hypothesis had been conducted.[144] In this study it was found that color-normal observers performed at a higher level than color-deficient observers

---

[143] B. Collins and J. Whittenburg. *Defective Color Vision, Filters, Film, and the Detection of Camouflaged Targets: An Annotated Bibliography*, US Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, March 1974.

[144] S. Wallace, P. Hexter, and S. Hecht. *Color Vision and Its Relation to the Detection of Camouflage*, Army Research Bulletin 43-6, 14 October 1943.

in detecting camouflaged targets from an airplane flying over the target area.

In an attempt to provide a definitive answer to the question of the effect of color vision on acquisition performance, Whittenburg and Collins[145] investigated the detection performance of 12 color-deficient observers (ten with a red-green color deficiency and two with a low color discrimination) and 24 color-normal observers in a field study involving military targets (tank, jeep, and towed howitzer). In addition, color deficiencies were simulated by the use of special lenses for 36 other observers. Their results indicated that no real differences in detection performance existed between the color-normal and the true color-deficient or the simulated color-deficient observers.

Dobbins and his associates at the Tropic Test Center in the Panama Canal Zone have investigated the related question of the effects of colored lenses on acquisition performance. The observers in these studies wore special lenses that filtered out selected spectral wavelengths. In the first of these studies,[146] 12 infantry soldiers wearing nonmagnifying yellow lenses detected stationary personnel targets in a tropical evergreen forest. Their detection performance was compared to that of 18 observers with unaided vision tested under the same conditions. The effect of the yellow lenses was to restrict the detectability of the personnel targets. In particular, ranges for these observers were shorter than for the observers with the unaided vision.

---

[145] J. Whittenburg and B. Collins, *op. cit.*

[146] D. Dobbins, M. Gast, and C. Kindick, *op. cit.*

In the second study of this series,[147] 24 infantry soldiers observed either with yellow lenses, with red lenses, with dichroic lenses,[148] or in an unaided (lenseless) mode. None of the lens conditions were found to affect target acquisition performance when compared to unaided vision. This was true for the 50 percent detection range thresholds, visibility gradients, and total detections.

Thus, these results tend to indicate that variations in color vision do not contribute to the detection process in natural field environments. However, it must be pointed out that only two of the above referenced studies involved personnel with true color deficiencies. Only one of the studies involving color-deficient personnel studied a ground combat detection situation and it employed only a few (12) color-deficient individuals. Further, it is questionable that colored lenses can simulate color vision defects.[149] As a consequence, it would appear that additional research is warranted concerning the question of the effect of variations in color vision on acquisition performance in field situations. For such research it would be appropriate to employ large sample sizes of color-deficient observers in a wider variety of situations involving varying military targets, both camouflaged and uncamouflaged. From this research it would be possible to obtain a better measure of any effects of color vision

---

[147] D. Dobbins and C. Kindick, *op. cit.*.

[148] These lenses were designed to reduce the transmission of light in the middle wavelengths of the visible spectrum, while allowing the normal transmission of light from the remainder of this spectrum. The net effects of the lenses tend to make the observer artificially color blind for the colors associated with the middle wavelengths, i.e., to make his vision dichromatic.

[149] B. Collins and J. Whittenburg, *op. cit.*

variations on detection performance. However, for the time being it would appear that the weight of the evidence is against variations in color vision having any significant effect on the acquisition process.

Age

Decline in visual functioning with age is often reported in the literature. However, significant decrements with increasing age do not generally occur until the late thirties or early forties. For example, Burg found that the visual field of men and women declined significantly after the age 30 to 40.[150] Studies of visual acuity with reference to increasing age find that acuity declines significantly after the age of 45.[151] These findings thus suggest that decrements in target acquisition performance as a function of age are not likely to be found unless the sample includes persons in their late thirties and early forties. In particular, it can be expected for relatively young military personnel without any severe eye defects, that acquisition performance will be unrelated to age.

Field studies of target acquisition support this hypothesis. Dobbins and his associates[152] report that in four separate studies age was found to be unrelated to threshold detection performance of enlisted military personnel. The average correlation between age and detection performance was .08. In all cases, these observers had been tested and were found to have

---

[150] A. Burg. "Lateral Visual Field as Related to Age and Sex," *Journal of Applied Psychology*, 1968, 52, 10-15.

[151] A. Lit. "Visual Acuity," in P. Farnsworth (ed.), *Annual Review of Psychology*, 1968, 19, 27-54.

[152] D. Dobbins, R. Chu, and C. Kindick, *op. cit.*

adequate visual acuity. The age range for these observers was from 18 to 35 years of age. Thus, for military situations in which the observer population is relatively young, age is not likely to be a factor in field acquisition performance.

Height

In combat situations the position from which an observer may view an area of ground for which he has responsibility can vary. Observations may be made from the prone position, the kneeling position, or from the standing position. In addition, an observer may be positioned in a tree or on top of a building while viewing his area of responsib.lity. The major effect of these changes in viewing position is to alter the height of the observer's eyes above the ground. The appearance of the targets may also be modified. To the extent that these changes reduce or increase the chances of obscuration by terrain or vegetation features, it may be expected that field acquisition performance will show corresponding increments or decrements. In general, field studies of the acquisition process support this conclusion.

For example, Anstey[153] concluded in a survey of field visibility measurement that greater daylight visibility distances were generally obtained from standing observers than from prone observers. For example, in a chaparral area, erect observers could obtain lines-of-sight of 500 or more feet [153 meters], while prone observers could obtain lines-of-sight of only 70 to 100 feet [21 to 31 meters]. In a mid-latitude forest, a human target wearing a white shirt was detected at an average range of 131.5 feet [41 meters] by an erect observer, while the same target was

---

[153] R. Anstey, *op. cit.*, 1964.

detected at an average range of 116.3 feet [35 meters] by a prone observer. These results clearly show that the height of an observer's eyes above the ground significantly affects his ability to acquire targets. In addition, taken together they suggest that the magnitude of this effect will depend on the type of terrain in which observations are made. In particular, it may be expected for relatively open terrain that the magnitude of the effect will be small, while for relatively cluttered terrains the magnitude of the effect will be large.

Caviness and Maxey[154] have also found that variations in observer height significantly affect daylight target acquisition performance. In their study three observer elevation conditions were studied: observer kneeling, observer standing erect, and observer standing erect on a three-foot platform. Their results indicated that as the height of the observer's head above the ground was increased, the range at which advancing personnel targets could be detected increased.

The above cited studies were conducted under conditions of daylight. They demonstrated collectively that increases in observer elevation were consistently associated with improvements in acquisition performance. Similar results have been obtained for acquisition tasks completed under nighttime illumination conditions. Taylor[155] studied the effect of observer height on acquisition performance under two illumination conditions: non-moon (starlight) and full-moon illumination. For the no-moon illumination condition no consistent effect of observer height on acquisition performance was found. However, for the full-moon illumination condition,

---

[154] J. Caviness and J. Maxey, *op. cit.*

[155] J. Taylor, *op. cit.*

it was found that standing observers were superior to kneeling observers, who in turn, were superior to prone observers in terms of their ability to acquire stationary personnel targets. These results indicate that only when the illumination level is sufficiently high will a relationship be obtained between observer height and acquisition performance. Further, they indicate that when the conditions are adequate for the relationship to manifest itself, it will be the expected direct relationship, i.e., larger ground-to-eye heights will be associated with better performance, while smaller ground-to-eye heights will be associated with poorer performance.

Walton[156] has also found that observer height is directly related to observer acquisition performance under low illumination conditions. In this study observers employed the Crew-Served Weapons Night Vision Sight (second generation). For observation under conditions of moonlight, prone observers detected fewer targets than standing observers. Targets in this study were both military personnel and military vehicles.

Taken collectively, these studies clearly indicate that the height of the observer's eyes above the ground is a significant factor in the acquisition process under both low and high ambient light conditions. In general, it has been demonstrated that as elevation of the observer's head above ground is increased from a prone height to a standing height, acquisition performance will show corresponding improvements. However, the level of ambient illumination must be somewhat above that of starlight for this relationship to appear. Further, the magnitude of this effect will become greater as the terrain in which observation is conducted becomes

---

[156]L. Walton, *op. cit.*

less cluttered and more open. That is, as terrain and vegetation features such as low brush, boulders, and minor undulations of the ground become less common, it can be expected that increases in the elevation of the observer's head will be accompanied by substantially greater improvements in his acquisition performance.

Past Experience

For any detection situation, the past history of experience which the observer brings with him into the situation may be expected to influence the extent to which he successfully performs an acquisition task. This past history of experience may take on at least two forms. It may be general experience gained through hunting and tracking in relatively uninhabited, "wild" areas, or through military experience in training or combat in a war zone. Alternatively, it may represent experience gained from structured classroom and field training classes in the subject or target acquisition. Since the effects of experience on acquisition performance have not been systematically researched to any great extent, only a tentative conclusion can be drawn with respect to the effects of this variable.

Dobbins and his associates[157] found in several studies of the acquisition process in tropical environments that years of military service was not significantly correlated with the 50 percent detection thresholds. The correlations obtained in these studies together averaged .09 and represented data from 108 observers. Experience ranged from 6 to 192 months of military service.

[157] D. Dobbins, R. Chu, and C. Kindick, *op. cit.*

Anstey,[158] on the other hand, has found that a professional hunter with many years of experience in tropical environments was able to locate prepositioned targets at longer distances and in shorter times than a non-hunter with little experience in tropical environments. Anstey[159] has also noted that experience in acquiring prepositioned targets in a mid-latitude forest leads to greater detection ranges and shorter decision times.

Taylor[160] studied the effects of three different types of night vision training (classroom, field, and classroom/field training) on the acquisition performance of observers under both no-moon and full-moon illumination conditions. In each case the training lasted for only two hours. The classroom training was designed to teach the observers the principles of observation at night and provided them with an opportunity practice these principles. The field training provided observers with an opportunity to practice the discrimination of personnel targets under no-moon illumination conditions. Finally, the classroom/field training was a combination of the classroom instruction and field practice. It was found, however, that the type of training did not affect acquisition performance. In this case, acquisition performance was measured as the percent correct detections made. It was suggested by Taylor that these results were due to the training not being sufficiently extensive.

---

[158] R. Anstey, *op. cit.*, 1963.

[159] R. Anstey, *op. cit.*, 1964.

[160] J. Taylor, *op. cit.*

Banks and his associates,[161] on the other hand, have found that special training designed to remedy identified deficiencies in target acquisition technique resulted in performance improvement for an acquisition task involving the use of visual aids. In particular, it had been found that poor search procedure was primarily responsible for a less than optimal level of acquisition performance. Special training was designed to teach observers how to conduct a timely and comprehensive search using two visual aids, the Starlight Scope and the Night Observation Device. Comparison of the acquisition performance of groups of observers trained under the standard and special training revealed that the special training groups detected more targets in shorter amounts of time than the standard training groups.

The results of these studies taken together suggest that for either general experience or training to be effective in the acquisition process requires that the experience or training be exceedingly relevant to the acquisition task at hand. That is, it can be expected that variations in either experience or training will be correlated with variations in acquisition performance only to the extent that these variations are associated with the production of or the differential functioning of specific skills which mediate the accomplishment of the acquisition task.

Motivational Variables

Motivation is a concept which is often employed to explain why the performance of a well-practiced task may show significant variability over time in the absence of any other changes in the situation defining the

---

[161] J. Banks, J. Sternberg, B. Cohen, and C. Debow, *op. cit.*

occasion for the performance of the task. Theoretically, motivational factors are thought to reflect internal conditions of the individual which have come to mediate the performance of a task or a set of tasks in some situation. In general, it is expected for those motivational conditions which are associated with task performance, that as the state of these conditions change, so will the quality of task performance manifested by the individual. As a consequence, it is important to know what motivating conditions are responsible for the maintenance of task performance in a situation and how changes in those conditions facilitate or inhibit performance in that situation.

None of the target acquisition literature reviewed reported data on the effects of motivational state on acquisition performance. It is evident, however, from close reading of this literature that the acquisition situations developed for study were consistently designed to keep internal motivation at a high level. For example, in many of the studies reviewed, military personnel served as observers and performed acquisition tasks within a military context. Therefore, it might be expected that the motivation to perform at an average or above average level was quite high in these cases. However, field research in a related visual problem area (detection of mines and boobytraps) suggests that variations in motivational states may have some impact on target acquisition performance in combat situations.

Bucklin and Rayner[162] studied the detection performance of enlisted military personnel as they traversed a simulated surface-laid munitions

---

[162] B. Bucklin and J. Rayner. *Development of a Detection Ability Index: I*, ESD IR No. 569 (Draft), Engineering Sciences Division, Feltman Research Laboratory, Picatinny Arsenal, Dover, New Jersey, April 1972.

minefield. The time required to traverse the minefield and the percentage of surface-laid munitions found were determined for each observer. In addition, the observers completed two paper-and-pencil tests designed to measure a variety of personality factors. Analysis of the data revealed that the amount of time spent in searching was directly related to the percentage of munitions found. Also, the analysis showed that certain of the personality factors measured were significantly correlated with detection performance. In particular, personality factors defined by scales reflecting placidity, lethargy, stability, and self-reliance were significantly related to detection performance. Specifically, it was found that the better detectors (those who detected a greater percentage of the targets) were low on the placidity and lethargy scales and high on the stability and self-reliance scales. These results clearly indicate that certain internal dispositions of the military personnel studied were related to their detection performance in this field situation.

A similar result was obtained by Maxey and his associates[163] in a study of the characteristics, aptitudes, and acquired skills required in the detection of mines and boobytraps in a field situation. In this study, enlisted military personnel traversed a field detection course and detected hidden mines and boobytraps. Observers were assessed with respect to the rated amount of effort they expended during the completion of the detection course. A significant direct relationship was found to exist between the amount of effort expended and the percentage of detections made by observers.

---

[163] J. Maxey, T. Powers, T. Jacobs, and G. Magner. *Identification of the Potential Characteristics, Aptitudes, and Acquired Skills Involved in Human Detection of Mines*, HumRRO Technical Report 73-18, Human Resources Research Organization, Alexandria, Virginia, August 1973.

Laboratory research also suggests that motivational factors may play a role in the acquisition process. Jones, Freitag, and Collyer[164] report that Bloomfield (in a laboratory study of visual search) found that incentive payments of money to observers affected their search performance in a positive way. Under conditions of incentive payments, the quality of search performance was significantly superior to the quality of search performance under conditions of practice without monetary incentive. They report that the "false alarm" rate also increased under conditions of incentive though not as much as the increase in the percentage of detections.

Pollack and Knaff[165] studied the influence of incentive conditions on vigilance task performance in a laboratory situation. In their study the task of the observer was to visually detect a change in deflection of a needle in a meter from a predicted course. Observers stood watch under one of three incentive conditions: neutral, reward, and punishment. Under the neutral condition, observers were told to do the best they could. Under the reward condition, they were told they would receive extra pay for good performance. Finally, under the punishment condition, failure to detect a signal resulted in an 0.5 second blast from a truck air horn. In addition to these conditions the vigilance task was completed under two levels of illumination: dark and light. Under conditions of dark, the observer watched a visual display in a darkened isolation booth, while under conditions of light, the observer worked in the presence of other observers in a brightly lighted room. Their results indicated that under

---

[164] D. Jones, M. Freitag, and S. Collyer, *op. cit.*

[165] I. Pollack and P. Knaff. "Maintenance of Alertness by a Land Auditory Signal," *Journal of the Acoustical Society of America*, 1958, 30, 1013-1016.

the punishment condition, the percentage of signals detected increased, detection times were reduced, and more false detections were made. Further, punishment was more effective for the poorer performing subjects than for the better performing observers. Also, effects of punishment were more pronounced under conditions of dark than light. Under the reward condition, performance was better than under the neutral condition, but the improvement was not as great as that produced by the punishment condition. Further, reward was more effective in the light condition than in the dark condition.

Dudek, George, and Ayoub[166] have also studied the effect of motivating incentives on vigilance task performance. In this investigation, some observers were given a fixed amount of academic credit for participation in the investigation, while other observers received academic credit whose magnitude depended on their task performance. Overall, the task performance of the observers who worked for a fixed amount of credit was inferior to the performance of the observers who worked under a performance-contingent credit schedule. Further, accurate task performance was found to be maintained much better over time by the contingent credit observers than by the fixed credit observers.

Thus, while it is currently unknown what specific effects variations in motivational conditions have on the acquisition process, relevant field and laboratory research suggests that motivational factors may be important in this process. Since it may be expected in a combat situation that

---

[166] R. Dudek, C. George, and M. Ayoub. "Performance Recovery and Man-Machine Effectiveness," in US Army Human Factors Research and Development, *Proceedings of the 15th Annual Conference*, November 1969.

changes in the motivational conditions of combat personnel will occur as the conditions and expectations of contact with the enemy change, it is important to know what effect a change in motivational conditions will have on acquisition task performance. As a consequence, this is an area that should receive some attention in future research on the acquisition process.

Summary

The purpose of this section of the report has been to present the results of a review of the literature of ground-to-ground target acquisition. For this review, target acquisition was considered as a generic term that covered not only the detection process, but also the process of recognition and identification. As such, the term *target acquisition* was employed as a neutral term whose meaning was largely dependent on the problem of targeting with which the reviewed studies were concerned.

Target acquisition is a military problem in that the ability of the infantryman, the forward observer, or the tank gunner to accurately acquire targets is a necessary prerequisite for the successful completion of his mission, i.e., the destruction or neutralization of the enemy's means to wage war. For example, in a given battlefield environment, a soldier may be engaged in one of two missions. On the one hand, he may be engaged in a defensive mission, in which case his task will be to defend an area from penetration or capture. On the other hand, he may be engaged in an offensive mission, in which case his task will be to find and destroy the enemy. In order to succeed in either of these missions, a soldier must be able to determine whether the enemy is present in his vicinity, that is, he must be able to acquire enemy targets. Thus, target acquisition and the ability of the modern soldier to successfully complete target acquisition tasks in a field environment is an important area from a military point of view.

The psychological problem as it relates to the military problem is one of identifying the relevant behavioral, environmental, and situational variables which affect the ability of human observers to perform optimally in a field target acquisition situation. In addition, such information is important for defining the types of field target acquisition situations, including targets (as to type, placement, etc.) appropriate for investigating the acquisition performance of human observers with and without acquisition aids.

A wide variety of parameters have been investigated in relation to target acquisition performance. These parameters fall into two basic groups of variables: stimulus (external) variables and organismic (internal) variables. The stimulus variables considered for their effect on the acquisition process fell into three broad categories: object (target) characteristics, environmental (background) characteristics, and task (situational) characteristics. The organismic variables considered for their effect on the acquisition process were those observer characteristics which could logically affect the observer's capability to perform the acquisition task, e.g., age, experience, motivation, visual acuity, etc. The effects of these variables are briefly summarized below:

Target characteristics. Eight acquisition parameters were considered under this heading: *target size, shape, color, brightness contrast, range, duration of exposure, motion, and speed.* Target size was found to be a factor in the acquisition process when the differences in relative size were large. For small relative differences in size, it was found that other factors were likely to be more important in the acquisition process.

Target shape was determined to be a factor in the acquisition process also, particularly when the target appeared in the context of non-target objects of similar shape. However, this conclusion was based on the results of laboratory work and, as such, remains to be verified under field conditions.

With respect to target color, it was found that it is not so much the object color that is critical for acquisition as it is the contrast of this color with the background in which the target appears. Therefore, color contrast, not color, is the important variable for the acquisition process for colored objects. In particular, it was found that as target color contrast increased, target acquisition performance also increased. Target brightness contrast was also found to be important in ground-to-ground target acquisition in the same manner as color contrast, i.e., as brightness contrast increased, acquisition performance improved.

Target range was found to be one of the most well-studied variables in the target acquisition literature. In general, it was found that as target-to-observer range increased, target acquisition performance decreased (when target size was held constant).

Target duration (length of time that a target is available for acquisition) was also found to be an important parameter in the target acquisition process. In particular, it was found that the relationship between duration and acquisition performance is a direct relationship. That is, increases in target exposure time are associated with improvements in acquisition performance.

Finally, target motion was found to be an important target acquisition parameter. In general, the literature in this area indicated that target motion, as well as the speed at which this movement occurred, facilitates acquisition performance. In particular, increments in target speed were found to be generally associated with improvements in target acquisition performance.

Environmental characteristics. Seven acquisition parameters were considered under this heading: *condition of the atmosphere, level of ambient illumination, terrain, vegetation, location, position of illumination source, and ambient temperature.* The condition of the atmosphere, i.e., its light transmission properties, was found to be significantly related to target acquisition, particularly for distant targets. In general, reductions in the light transmitting capabilities of the atmosphere were found to be associated with decrements in target acquisition performance.

The effect of ambient illumination on target acquisition was found to be well studied. Overall, the literature indicated that as the level of ambient illumination is increased from very low levels to moderately low levels, there is substantial improvement in acquisition performance. However, it appears that as illumination is further increased from moderately low to higher levels, improvement in acquisition performance cannot be generally expected. Thus, for this variable, it seems that illumination level is a more important variable for low illumination acquisition than for high illumination acquisition.

Both inter- and intra-terrain variations were found to affect the detectability of targets. The major effect of difference between terrain was found to be in terms of target obscuration and restrictions in the ranges at which targets could be acquired. Within a given terrain the major effect was found to be in terms of interactions of specific terrain features with specific target characteristics, such as contrast and duration.

The acquisition performance of observers in vegetated areas was found to vary with the season of the year, the height of vegetation, the type of vegetation, and the density of vegetation. In general, it was found that as these factors led to increased conditions of obscuration, target acquisition performance showed progressive decrements.

With respect to target location, it was found that this is a factor in the acquisition process when few lines-of-sight exist between the target when search patterns lead to infrequent glimpses of areas in which targets are located. Target location is also a factor when observer expectations about target location do not correspond to actual target locations. It was also found that the position of the illumination source (in terms of both elevation and azimuth) significantly affects the acquisition process, particularly for targets which have intrinsically low contrast with the environmental background. The results were quite clear. As targets were directly lighted from either the front or the rear, acquisition performance improved.

Due to the lack of adequate studies conducted under varying temperature conditions, it was not possible to exactly determine the effect of temperature variations on acquisition performance. However, a review of studies involving visual tasks completed under various conditions of cold and heat suggested that this variable be of some importance for the acquisition process in field situations. In particular, there was some evidence found which suggested that extreme conditions of heat and cold may adversely affect the performance of visual tasks.

Task characteristics. Five acquisition parameters were considered under this heading: *observer movement, size of search area, practice effects, search method, and duration of observation.* Observer movement with respect to the target was found to be a significant factor in the acquisition process. In particular, it was found that observer movement affects the target acquisition process only when the target also moves. For stationary targets, observer movement was found to provide only a slight advantage in the acquisition process.

The results of both the laboratory and field research reviewed indicated that reductions in the size of the search area was generally associated with improvements in the percentage of targets detected or with reductions in the amount of time required to detect targets. In addition, these results indicated that the exact effects of reductions in search area size appear to be dependent upon the brightness of the target and the ambient illumination level of the surround as well as target exposure time.

With respect to the effects of practice on acquisition performance, the research findings were somewhat contradictory. In some cases, practice at target acquisition facilitated performance, while in other cases it did not. The basis for these contradictory findings was not immediately clear. At this point, without further research, it can only be concluded that practice effects may occur. As a consequence, the possibility of such effects must be taken into account during the design of investigations of the acquisition process.

Overall, the results of the studies reviewed concerning variations in search strategy clearly indicated that the type of strategy employed by an observer can (under some conditions) affect the quality of his acquisition performance. Thus, in studies of the acquisition process, data should be recorded which reflect the strategy employed by the observer during the completion of the acquisition task. By such a procedure any differences in acquisition performance due to search strategy variations may be accounted for and/or controlled. Further, if a particular search strategy has been tested and validated with respect to its effectiveness, then it may be appropriate to require observers to use this strategy to optimize test results.

However, the literature does not indicate any clear-cut superiority for either free search or specified search strategies. The results of the studies conducted by some investigators suggest that the effectiveness of specific search strategies may be dependent upon both target and environmental variables. This would imply that the failure to find a relationship between variations in search strategy and acquisition performance (as this occurred in some instances) may have been in part due to the failure to control relevant target and environmental variables.

Collectively, the results of the investigations designed to assess the effects of duration of observation on target acquisition indicated that when continuous operations involve the loss of sleep, performance decrements in completion of an active acquisition task can be expected. However, when some opportunity for rest is allowed or sleep loss is not very large, performance decrements are not likely for active acquisition.

However, experimental evidence was found which indicated that when the acquisition situation approximates a vigilance task situation (in terms of such factors as low signal rate), performance decrements may be expected, even when loss of sleep is not a factor.

Observer characteristics. Six observer parameters were considered under this heading: *visual acuity, color vision, age, height (above ground level), past experience, and motivation.*

Relatively little research has been conducted to investigate the effect of variations in observer visual acuity on acquisition performance in ground-to-ground target acquisition situations. In particular, the present review located only four studies relative to this problem area. Collectively, the results of these studies indicated that as the level of visual acuity is increased, target acquisition performance show progressive improvements (i.e., more targets are detected sooner). This was found to particularly true for targets located relatively near (less than 900 meters) the observer.

The review of studies involving color vision tend to indicate that variations in color vision do not contribute to the detection process in natural field environments. However, it must be pointed out that only two of the studies reviewed involved personnel with true color deficiencies. Only one of the studies involving color-deficient personnel studied a ground combat detection situation and it employed only a few color-deficient individuals. As a consequence, it would appear that additional research is warranted concerning the question of the effect of variations in color vision on acquisition performance in field situations. For such research it would be appropriate to employ larger sample sizes of color-deficient observers in a wider variety of situations involving varying military targets, both camouflaged and uncamouflaged. From this research it would be possible to obtain a better measure of any effects of color vision variations on detection performance. However, for the time being, it would appear that the weight of the scientific evidence is against the importance of this variable for target acquisition performance.

Very few studies were identified which addressed the effect of age on visual performance. Overall, these studies indicated that age was a factor in visual performance for only older (over 35 years) populations. Thus, for military situations in which the observer population is relatively young, age is not likely to be a factor in field acquisition performance.

Taken collectively, the results of studies involving variations in observer height (above ground level) clearly indicate that this parameter is a significant factor in the acquisition process under both low and high ambient light conditions. In general, it has been demonstrated that, as elevation of the observer's head above ground is increased from a prone height to a standing height, acquisition performance will show corresponding improvements. However, the level of ambient illumination must be somewhat above that of starlight for this relationship to appear. Further, the magnitude of this effect will become greater as the terrain in which observation is conducted becomes less cluttered and more open. That is, as terrain and vegetation features, such as low brush, boulders, and minor undulations of the ground, become less common, it can be expected that increases in the elevation of the observer's head will be accompanied by substantially greater improvements in his acquisition performance.

With respect to the effect of past experience, the results of the studies reviewed suggest that for either general experience or training to be effective variables in the acquisition process, either the experience or training must be exceedingly relevant to the task at hand. In particular, it can be expected that variations in either experience or training will be correlated with concomitant variations in acquisition performance only to the extent that these variations are associated with the production of or the differential functioning of specific skills which mediate the accomplishment of the acquisition task.

It is currently unknown what specific effects variations in motivational conditions have on the acquisition process. However, relevant field and laboratory research suggests that motivational factors may be important in this process. In particular, this research suggests that variations in certain individual dispositions may be associated with variations in the quality of visual task performance. Further, this research indicates the variations in the motivational factors governing the conditions of task performance for a visual task may also be associated with variations in the quality of task performance. Since it may be expected in a combat situation that changes in the motivational conditions of combat personnel will occur as the conditions and expectations of contact with the enemy change, it is important to know what effect a change in motivational conditions will have on acquisition task performance. As a consequence, this is an area that should receive some attention in future research on the acquisition process.

Implications of the literature. The major purpose of this review was to identify from the published research those variables which have been empirically shown to affect visual acquisition performance in ground-to-ground target situations. Over 300 reports, books, and journal articles were acquired and examined during the course of the search for materials relevant to the visual acquisition problem. Eighty-four of these were finally selected for an intensive review. Analysis of this material yielded a total of 24 variables which are likely to be important in the visual acquisition process for ground-to-ground target situations. Table 2 lists these variables according to the type of factor they represent, e.g., target characteristics, environmental characteristics, etc.

From an overall appraisal of the literature reviewed, it is possible to draw several important conclusions. First, and most obvious, is the fact that the target acquisition process, in any given situation, is governed by a wide variety of variables. These variables may act independently of each other or in conjunction with each other to affect the process. For each of the variables considered in this review, it was generally possible to state the impact of the variable on the acquisition process. As a consequence, it is most important for field researchers working in this problem area to take the factors listed in Table 2, and their likely effects, into account. This is most important during the design and execution phases of any such research. It is only through such a careful specification of target acquisition factors that the results of this type of research may be adequately interpreted and understood. Further, researchers new to this problem area can ensure that their research designs and experimental procedures will adequately address the practical questions for which answers are desired. Finally, in some cases, it may prevent researchers from unnecessarily covering research ground which has already been adequately studied.

Table 2. Behavioral Variables Affecting Ground-to-Ground Visual Target Acquisition

STIMULUS VARIABLES

Target Characteristics

- Size
- Shape
- Color Contrast
- Brightness Contrast
- Range
- Duration of the Exposure
- Presence of the Motion
- Speed

Environmental Characteristics

- Condition of the Atmosphere
- Level of Ambient Illumination
- Terrain
- Vegetation
- Location of Target in the Terrain
- Illuminant Position
- Ambient Temperature

Task Characteristics

- Movement of the Observer
- Size of Search Area
- Practice
- Search Strategy
- Duration of Observation

OBSERVER VARIABLES

Visual Acuity

Observer Height (Eye Level Above the Ground)

Past Experience and Training

Motivation

Second, due to limitations of the state-of-the-art, it is for the most part not possible to go beyond general statements concerning the effect of a particular acquisition parameter on target acquisition performance. This is because very few acquisition studies have been designed to evaluate target acquisition performance as a function of many different levels of a given variable. Most of the research conducted in this area has been "one-shot" in nature and designed to establish whether or not a particular level or a limited set of levels of a given variable is important in the acquisition process. Further, variations from one study to the next in such factors as targets, terrain, illumination, target duration, search techniques, and subject populations have been considerable. As a consequence, it was only possible to establish if a particular variable was important in the process and the general conditions for which this was true.

Third, as indicated in the body of the review, many of the variables listed in Table 2 were found to interact with each other to affect the outcome of the acquisition process in a given situation. Unfortunately, due to the limitations of the target acquisition literature, it was not possible to determine to what extent dependencies exist among all of the variables in Table 2. However, since it is likely that such dependencies do exist, it is important that the possibility of these dependencies be taken into account during the design and execution of field research.

Fourth, there are many gaps in the target acquisition literature. Research in the past has generally been undertaken to answer specific questions posed by specific users. Different investigators have employed procedures and target situations designed to answer these specific and generally limited questions. In other words, research has been guided more by contingency than by principle. As a result, data are simply not available to predict acquisition performance from knowledge of the parameters involved in a given situation. This does not mean that the effects of some variables have not been investigated thoroughly. They have, but others have been largely neglected. Thus, it is possible to extrapolate results from one situation to another only in the most general way.

The implication of these findings is clear. As discussed above, it is possible from the literature to specify what independent variables are likely to affect an observer's ability to successfully perform an acquisition task in at least some situations. Further, in a general way, it can be predicted what the nature of this difference will be, i.e., the expected relationship between the independent variables and performance can be specified at a general level. However, the state-of-the-art is not at the point where it is possible to write some type of mathematical expression that will allow a researcher to make accurate predictions about the effects and interactions of selected acquisition variables for all specific acquisition situations. What is needed is a general theory of the target acquisition process which is based on a logical and comprehensive program of empirical research designed to provide definitive information about (a) the relative importance of each target acquisition parameter, (b) the exact mathematical relationships between performance and the various acquisition parameters for all parameters considered simultaneously, and (c) the specification of the interactive effects of important acquisition parameters over all relevant acquisition situations. With such a theory, the limitations identified by this review would cease to exist and it would be possible to utilize the literature of this area in a much more comprehensive manner than now is possible.

CHAPTER 3

THE THREAT ON THE MODERN BATTLEFIELD

The purpose of this chapter is to *identify and describe the targets and operational tactics likely to be encountered by US ground forces in a future military conflict.* In order to accomplish this objective, it was necessary to make several assumptions with respect to (a) where and against what military forces a future conflict would be fought by US forces, and (b) at what level (low-, mid-, or high-intensity) such a conflict would be waged. An overview of current US military doctrine as discussed in recent Field Manuals (FMs), Training Circulars (TCs), and TRADOC Bulletins, e.g., FM 17-50,[1] TC 7-24,[2] and TRADOC Bulletin 1 (U)[3] suggests that Soviet/Warsaw Pact forces or forces equipped and trained by the Soviet Union constitute the primary threat for the US Army in the near future. Further, due to the close proximity of US/NATO and Soviet/Warsaw Pact forces in central and northern Europe, it is generally accepted that any major milicary conflict involving the US Army in the near future would be centered in these areas. Finally, consideration of current US and Soviet military doctrine (to be discussed below) suggests that an armed confrontation between these nations will result in both conventional (mid-intensity) and nuclear (high-intensity) engagements.

---

[1] FM 17-50. *Attack Helicopter Operations* (Draft), Department of the Army, US Army Armor School, Fort Knox, Kentucky, October 1975.

[2] TC 7-24. *Antiarmor Tactics and Techniques,* Department of the Army, US Army Infantry School, Fort Benning, Georgia, 30 September 1975.

[3] TRADOC Bulletin 1 (U). *Range and Lethality of US and Soviet Antiarmor Weapons,* Department of the Army, US Army Training and Doctrine Command, Fort Monroe, Virginia, 30 September 1975.

Operating under these assumptions, literature addressing the threat posed by the Soviet/Warsaw Pact nations was sought. Since it was desired that this review be available to the scientific community as a whole, this search was directed to the identification of unclassified sources of information. Even with this constraint, a wide variety of both military and non-military publications was found which provided a relatively consistent and complete description of Soviet/Warsaw Pact doctrine and equipment. Therefore, the omission of classified sources from the review is not seen as detracting from the validity of the description of the threat. From the review, it was possible to identify (a) the types of military ground targets US ground forces must acquire in a future US-Soviet/Warsaw Pact confrontation, and (b) the tactics and likely deployment of these targets in such a confrontation. The remainder of this chapter will be devoted to the discussion of this information in detail.

Threat Forces in Northern and Central Europe

The Soviet/Warsaw Pact ground forces currently deployed in northern and central Europe (and in adjacent western USSR military districts) are substantial, both in terms of numbers of personnel and divisions. For example, Soviet forces in this area and in adjacent Soviet territory number approximately 610,000 troops. Non-Soviet threat forces (East German, Polish, and Czechoslovakian forces) in this area number approximately 300,000 troops. These figures represent both combat and direct support personnel. Thus, collectively, there are 910,000 Warsaw Pact troops ready for commitment to a confrontation in northern and central Europe.[4]

---

[4]"The Theatre Balance Between NATO and the Warsaw Pact," in *The Military Balance 1974-1975*, Institute Staff, The International Institute for Strategic Studies, London, England, 1974, pp 95-102.

Overall, these ground forces are organized into 70 divisions. Of these, 43 are Soviet divisions, while the remaining 27 are East German (six divisions); Polish (13 divisions); and Czechoslovakian (eight divisions) divisions. The bulk of the 43 Soviet divisions are stationed in Eastern Europe (27 divisions), while the remaining 16 Soviet divisions are stationed in nearby areas of western USSR. Thus, excluding the Soviet forces located in adjacent USSR territory, there are a total of 58 combat-ready Warsaw Pact divisions (27 Soviet and 27 non-Soviet divisions) available for immediate combat in northern and central Europe.[5] Further, these forces are, for the most part, armored or mechanized infantry. For example, the 27 Soviet divisions in central Europe are split into 14 armored divisions and 13 mechanized infantry divisions. Czechoslovakian forces are split into five armored divisions and three mechanized infantry divisions. East German forces are split into two armored divisions and four mechanized infantry divisions. Finally, Polish forces are split into five armored divisions, six mechanized infantry divisions, and two infantry/airborne divisions.[6]

However, these figures only reflect frontline combat power deployed on the ground in normal peacetime circumstances. Assuming that Warsaw Pact forces were to move reinforcements into this area and initiated mobilization of first-line reserves, the above figures would be altered upward greatly. For example, it has been estimated that the 27 combat-

[5] *Ibid.*

[6] S. Canby. *The Alliance and Europe. Part IV. Military Doctrine and Technology*, Adelphi Papers, No. 109, The International Institute for Strategic Studies, London, England, Winter 74/75.

ready Soviet divisions deployed in this area could be incremented to between 70 and 80 divisions in a few weeks if mobilization were relatively unimpeded.[7] Including the non-Soviet forces that are normally kept at a less than full combat-ready level (four divisions), the total number of Warsaw Pact divisions that could be available after a relatively unimpeded mobilization would be approximately 84 divisions. Thus, it is clear that the potential threat in Europe is quite large both in terms of numbers of ready divisions and reinforcement divisions.

Threat Equipment

In most areas of the world and, in particular in Europe, threat forces are predominantly armored. This is reflected in the large number of tanks (approximately 20,000 in northern and central Europe for both Soviet and non-Soviet threat forces[8]), armored fighting vehicles, self-propelled artillery, and supporting mobile equipment that are in the threat forces inventory. In addition, these forces are equipped with highly sophisticated air defense weapons that complement each other to form an "air defense umbrella" over their area of operations. Finally, many individual threat soldiers are armed with first-generation antitank guided missiles capable of hitting tank-sized targets out to 3500 meters. The remainder of this section will discuss these aspects of threat forces in some detail with an emphasis on their relevance for a target presentation methodology.

Threat armor. Since the end of World War II (WWII), Soviet forces have substantially increased their emphasis on armored fighting vehicles,

---

[7] "The Theatre Balance Between NATO and the Warsaw Pact," *op. cit.*

[8] *Ibid.*

e.g., tanks and infantry combat vehicles. For example, "in 1945, tanks comprised less than six percent of USSR ground forces. By the mid 1970s, tanks were more than 25 percent."[9] In this same time frame, the number of tanks in each Soviet-type motorized rifle division was increased sixteen times over the number possessed by comparable WWII Soviet units.[10] Further, during this period of time, Soviet-equipped forces were provided with large numbers of armored personnel carriers, over thirty-seven times the number found in the 1945 Soviet ground army.[11] As a consequence, today's Soviet forces are basically composed of tank and motorized infantry units. Thus, it may be expected that US forces will most likely encounter these types of units in a mid- to high-intensity environment in any future military confrontation with Warsaw Pact forces.

According to TC 7-24,[12] the major armored vehicles deployed within Soviet tank and motorized rifle divisions are: (a) the *T-55* and *T-62* main battle tanks, (b) the *PT-76* light amphibious tanks, (c) the *BTR-60PB* and *BMP* armored personnel carriers, (d) the *BRDM* reconnaissance vehicle, and (e) the *ZSU-57-2* and *ZSU-23-4* mobile air defense weapon systems. These armored vehicles are considered by current US Army doctrine as providing the major threat to, and antiarmor targets of particular importance to, US armor and mechanized infantry forces.

---

[9]TRADOC Bulletin 8. *Modern Weapons on the Modern Battlefield*, Department of the Army, US Army Training and Doctrine Command, Fort Monroe, Virginia.

[10]*Ibid.*

[11]*Ibid.*

[12]TC 7-24, *op. cit.*

As indicated above, two types of main battle tanks are employed by Soviet ground forces: the *T-55* and *T-62* tanks. The *T-55* tank series was developed after WWII. It is armed with a 100mm rifled-bore main gun and fires APHE (Armor Piercing High Explosive), HEAT (High Explosive Anti-tank), and HE (High Explosive) ammunition.[13] In addition, it is equipped with a 7.62mm bow machinegun and a 7.62mm coaxial machinegun. Also, some models mount a 12.7mm heavy machinegun for air defense purposes.[14] Finally, this tank is equipped with an infrared night sight and has a snorkle capability of up to five meters. It has a speed of 50 kmph and a cruising range of 500 km.

The *T-62* tank is currently replacing the *T-55* tank in Soviet tank and motorized rifle units. In terms of armament and size, it is very similar to the *T-55* tank except that it mounts a 115mm smoothbore main gun. This main gun fires both HEAT and APFSDS (Armor Piercing Fin Stabilized Discarding Sabot) rounds.[15] In particular, the APFSDS round is the fastest tank gun round in the world with a muzzle velocity of approximately 5300 feet [1610 meters] per second.[16] In addition to the main gun, the *T-62* is armed with a 7.62mm coaxial machinegun and (on some models) a 12.7mm heavy machinegun.[17] Like the *T-55*, it is equipped with an infrared night sight, has a five-meter snorkle capability, a speed of 50 kmph, and a cruising range of 500 km.

---

[13] *Ibid.*

[14] TC 17-17. *Gunnery Training for Attack Helicopters* (Draft), Department of the Army, US Army Armor School, Fort Knox, Kentucky, 1 August 1975.

[15] TC 7-24, *op. cit.*

[16] TRADOC Bulletin 1, *op. cit.*

[17] TC 17-17, *op. cit.*

In addition to these tanks (which are classed as light tanks), Soviet forces have in their inventory a heavy tank (the *T-10*) which mounts a 122mm main gun. It is also armed with a coaxial machinegun (either a 14.5mm or 12.7mm gun) and a heavy machinegun (either a 12.7mm or 14.5mm gun) mounted on top of the turret. It has a night vision capability and is equipped with a snorkle for deep fording.[18] Its speed is somewhat less than 50 kmph and its cruising range is less than 500 km.

Finally, these forces employ a light-weight, amphibious tank-like vehicle (the *PT-76*) which is equipped with a 76mm main gun designed to fire APHE, HEAT, and HVAP (High Velocity Armor Piercing) rounds and a 7.62mm coaxial machinegun. In water it has a speed of approximately 10 kmph,[19] while on land it has a speed of about 40 kmph. Its cruising range is approximately 250 km. Some models are equipped with a 12.7mm Heavy machinegun for air defense. This tank is normally found in front of the main body of a ground force performing reconnaissance functions.[20]

In addition to these tanks, two new varieties are currently being developed by the Soviet army. The first, a new medium tank called the *T-70*, is approximately the size of the *T-62* series tank. Exterior changes indicate that crew positions inside the tank have changed, e.g., the driver's hatch is now located in the middle of the hull, the gunner is now on the right of the main gun, and the loader is now on the left. Addi-

---

[18] *Ibid.*

[19] TC 7-24, *op. cit.*

[20] FM 17-50, *op. cit.*

tionally, it has six evenly spaced wheels (compared to the five wheels of the *T-62* series tank) and four support rollers.[21]

The second is a new light tank, called the *BMD*, which resembles the *BMP* armored personnel carrier (to be discussed below). It has the same turret as the *BMP* and, in addition, has a *Sagger* antitank missile launch rail. Like the *BMP*, it is amphibious. While it is somewhat smaller than the *BMP* in both length (5.3 meters *versus* 6.3 meters) and width (2.65 meters *versus* 3.65 meters), its height is about the same as the *BMP* (1.85 meters *versus* 1.83 meters). Finally, it has a ground speed of about 60 kmph. [22]

Soviet forces employ at least two basic types of armored personnel carriers: the *BTR* and the *BMP*. The *BTR-60PB* (the most current in the *BTR* series) is an eight-wheeled, lightly armored, turreted combat vehicle. It is armed with a 14.5mm heavy machinegun and a 7.62mm coaxial machinegun. It has an amphibious capability (speed in water is approximately 10 kmph) and carries a crew of two with eight passengers (infantrymen).[23] It has a cruising range of approximately 450 km and a speed of 80 kmph on land.

The basic *BMP* is a tracked, lightly armored, turreted combat vehicle. It is armed with a 73mm smoothbore main gun and a 7.62mm machinegun. It also has an amphibious capability (speed in water is approximately eight kmph) and carries a crew of three with eight passengers (infantrymen).[24]

---

[21] R. Pretty (ed.). *Jane's Weapon Systems* (7th ed.), New York: Franklin Watts, Inc., 1975.

[22] *Ibid.*

[23] TC 7-24, *op. cit.*

[24] *Ibid.*

On land it can attain speeds of 55 kmph and has a cruising range of 300 km. Both the *BMP* and *BTR-60PB* have firing ports designed to allow infantry personnel to fire from within the vehicle whie it is on the move.[25] In addition, the *BMP* has a *Sagger* antitank guided missile launch rail mounted above the main gun. It carries a basic load of four to five *Sagger* missiles.[26] Also, the *BMP* carries two *SA-7 (Grail)* surface-to-air missiles (which are similar in operation to the US Army *Redeye* missile system).[27]

The *BTR-60PB* and *BMP* combat vehicles are generally employed to move infantry personnel into the battle area and to allow them capability to fight on the move without having to dismount. The *BMP* is also used during reconnaissance activities to provide covering fire for advancing *PT-76* or *BRDM* armored vehicles. It has been pointed out by one source[28] that the *BTR* series vehicles have recently been replaced to some extent by later models of the *BMP*, in particular the *BMP-76PB* which mounts a 76mm smoothbore main gun and the *Sagger* missile system. However, it can probably be expected that within Warsaw Pact forces overall, the *BTR* series vehicles are still in evidence.

In addition to the *PT-76* amphibious light tank mentioned above, Soviet forces also employ a four-wheel drive vehicle (the *BRDM*) with an

---

[25] *Ibid.*

[26] TRADOC Bulletin 2 (U). *Soviet ATGMs: Capabilities and Countermeasures*, Department of the Army, US Army Training and Doctrine Command, Fort Monroe, Virginia, April 1975.

[27] FM 17-50, *op. cit.*

[28] J. Erickson. "Soviet Military Capabilities in Europe," *Journal of the Royal United Services Institute for Reference Studies*, Great Britain, March 1975.

amphibious capability for reconnaissance activities. Further, this vehicle, modified in a number of ways, is employed in other combat roles, e.g., command vehicle, NBC (Nuclear, Bacteriological and Chemical) reconnaissance test vehicle, antiarmor vehicle, and air defense vehicle.[29] One reason for this multiple role capability lies in its good cross-country mobility. This mobility has been provided by a centralized tire pressure regulation system and the presence of two sets of belly wheels which can be lowered to aid flotation and assist in crossing gaps in terrain or natural obstacles.[30] Its maximum land speed is about 100 kmph and it has a cruising range of 750 km.

The *BRDM* has been produced in five similar models. The first, the basic *BRDM*, has no armament or turret, carries a crew of five, and is employed as a scout car. The second, the *BRDM-2* is turreted and mounts a 14.5mm heavy machinegun and a 7.62mm coaxial machinegun. It carries a crew of three or four men. It is also employed as a scout car. The third, the *Sagger-BRDM*, has a modified *BRDM* chassis designed to carry a rack containing the *Sagger* missiles.[31] When deployed (usually in defilade and exposing a one-by-four foot cross section), the rack is raised from inside the vehicle and set for firing. In this mode, it carries a two-man crew and a complement of 14 *Sagger* missiles.

In the fourth model, the *Swatter-BRDM*, the basic *BRDM* chassis has been modified to carry a rack containing *Swatter* antitank guided missiles. This rack is also carried within the vehicle during cross-country travel

---

[29]FM 17-50, *op. cit.*

[30]*Ibid.*

[31]TRADOC Bulletin 2, *op. cit.*

and is raised out of the vehicle for firing. In this mode, it carries four *Swatter* missiles and a crew of two men.[32]

Finally, in the fifth model, the *SA-9-BRDM*, the basic *BRDM* chassis has been fitted with a quadruple canister missile launcher placed on the vehicle roof and attached to the vehicle turret. *SA-6 (Gaskin)* missiles (improved versions of the *SA-7* surface-to-air missiles) are carried and launched from this roof rack.[33]

Within Soviet tank and motorized rifle divisions, there are two main armored air defense systems: the *ZSU-57-2* and the *ZSU-23-4* tanks. The *ZSU-57-2* system has a long range, optically-controlled set of twin 57mm antiaircraft cannons mounted in an open-topped turret. The turret is set into a modified *T-54* tank chassis. It is usually deployed with forward ground elements in batteries of six vehicles. It has a firing capacity (rate of fire) of between 105 to 120 rounds per minute per gun and a tactical antiaircraft range of approximately four kilometers (at high angles). Its effectiveness is dependent on the gunner's ability to optically acquire and track targets.[34,35]

The *ZSU-23-4* system has a radar/optically controlled set of four 23mm guns mounted in a fully protected turret. The turret is set into a light armor chassis. The fire-control system is fully integrated. Part of this system is an onboard radar mounted at the rear and on top of the gun turret. This air defense system is usually deployed with forward

---

[32] *Ibid.*

[33] FM 17-50, *op. cit.*

[34] *Ibid.*

[35] TC 17-17, *op. cit.*

elements and is often linked with the *SA-6 (Gainful)* surface-to-air missile system to form a complementary interlock in the Soviet "air umbrella." It has a firing capacity of 800-1000 rounds per minute per gun and a tactical antiaircraft range of 3.0 kilometers with radar and 2.5 kilometers without radar.[36,37]

Figures 3 and 4 present the typical deployment of selected armored vehicles discussed in this section for the cases of a deliberate (Figure 3) and a hasty defense (Figure 4). Figure 5 presents the typical deployment of selected armored vehicles discussed in this section for the case of an advance to attack. The information for these figures was obtained from TC 7-24.[38]

Threat antiarmor weapon systems. In the previous section (Threat Armor) it was pointed out that since the end of WWII, Soviet ground forces have increasingly emphasized the use of tanks and mechanized infantry. Concurrent with this increased emphasis on armored warfare, Soviet forces have recognized the need for effective countermeasures against ground forces also equipped with armored fighting vehicles. As a consequence, a variety of weapon systems (smoothbore tank cannon, antitank guided missiles, and rocket-propelled grenades) have been developed for defeating opposing armored forces in ground combat situations. In general, these weapon systems are very accurate and highly lethal. Collectively, they mesh to provide an impressive antiarmor capability out to 3500 meters. Since these weapons must be neutralized for effective armor

---

[36]FM 17-50, *op. cit.*

[37]TC 17-17, *op. cit.*

[38]TC 7-24, *op. cit.*

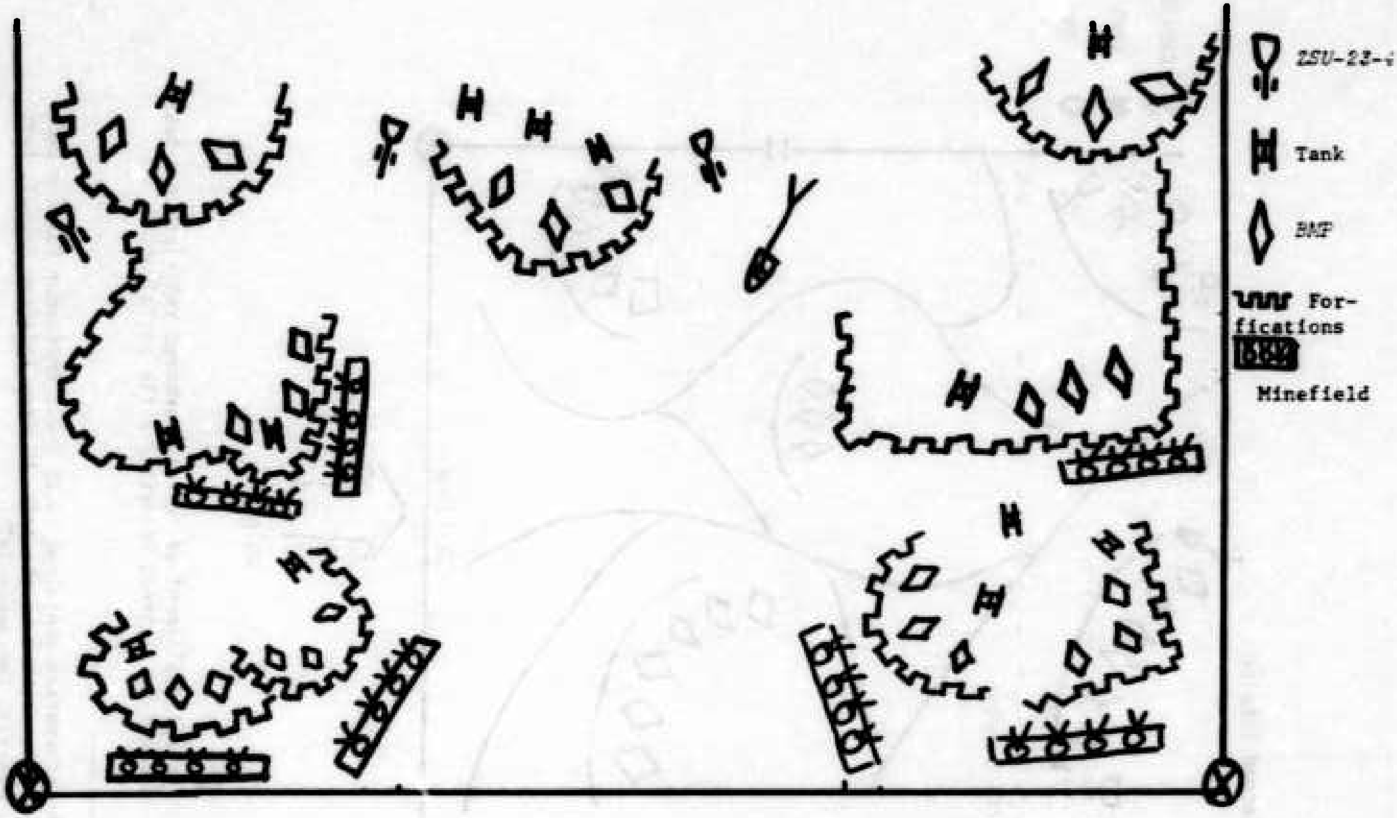


Figure 3. Typical deployment of selected armored vehicles in a deliberate defense by a threat motorized rifle battalion (Main Defense Zone).[39]

[39]Based on information contained in TC 7-24, *Antiarmor Tactics and Techniques*, Department of the Army, US Army Infantry School, Fort Benning, Georgia, 30 September 1975.

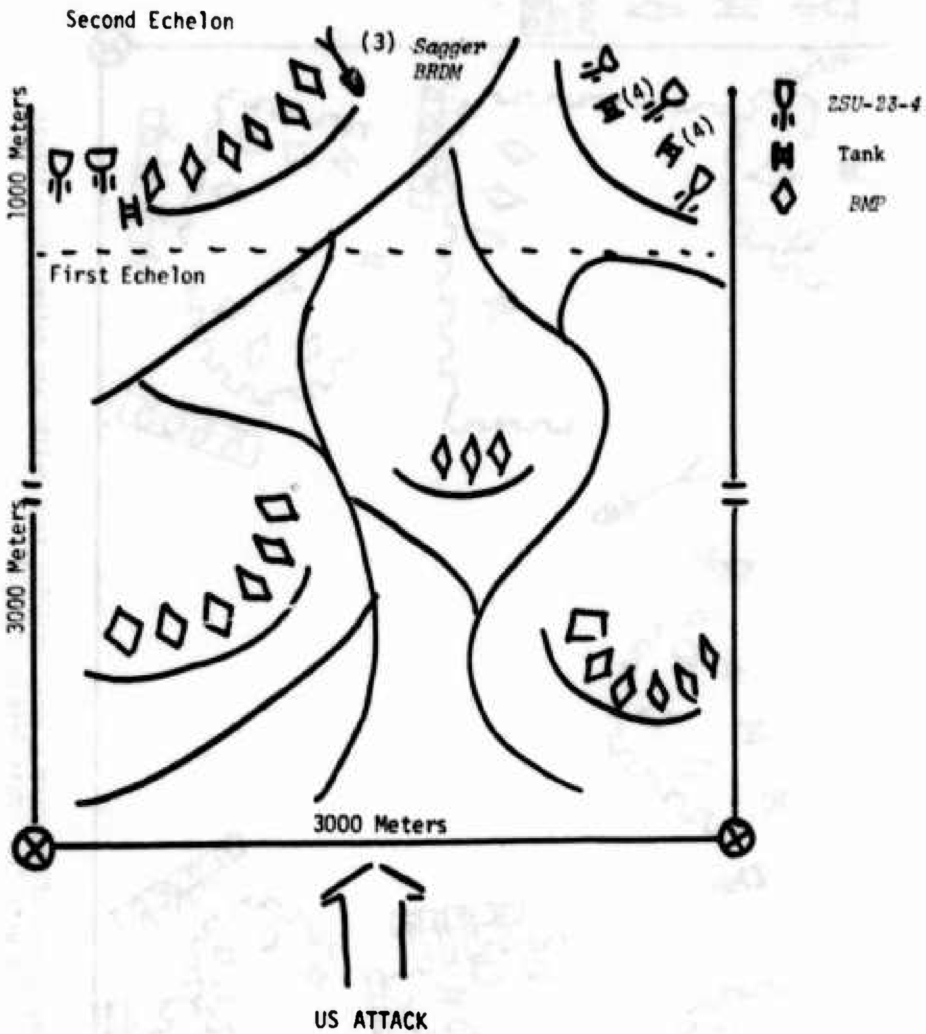


Figure 4. Typical deployment of selected armored vehicles in a hasty defense by a threat motorized rifle battalion.[40]

---

[40] Based on information contained in TC 7-24, *Antiarmor Tactics and Techniques*, Department of the Army, US Army Infantry School, Fort Benning, Georgia, September 1975.

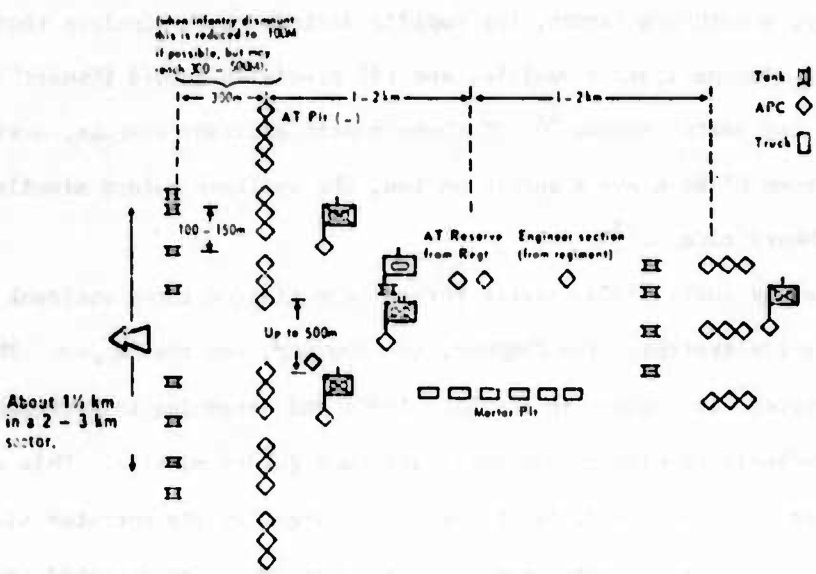


Figure 5. Typical deployment of selected armored vehicles in an attack formation by a threat motorized rifle battalion.[41]

---

[41]Reproduced from TC 7-24, *Antiarmor Tactics and Techniques*, Department of the Army, US Army Infantry School, Fort Benning, Georgia, 30 September 1975.

operations by an opposing force, they will be priority objectives for target acquisition systems. Therefore, it is appropriate to discuss these weapons in terms of their effectiveness and their expected deployment on the modern battlefield.

Modern technology has provided at least four types of effective antitank weapons: (a) the antitank guided missile, (b) the low recoil, flat trajectory, smoothbore cannon, (c) rapidly distributable minelets that can temporarily incapacitate a vehicle, and (d) precision guided ("smart") artillery and mortar rounds.[42] Of these modern antitank weapons, Soviet ground forces place heavy emphasis on two, the antitank guided missile and the smoothbore cannon.[43]

Since the early 1950s, Soviet forces have fielded three antitank guided missile systems: the *Snapper*, the *Swatter*, and the *Sagger*. The *Snapper* system was fielded in the late 1950s and resembles in performance the French/American wire-guided *SS-11* antitank guided missile. This missile (after it is launched) is piloted to a target by its operator via electronic instructions sent from a control box over wire attached to the missile. Approximately 500 meters are required for the operator to gain control over the missile after it has been fired. After this point, the likelihood of the missile hitting its target is highly dependent on the skill of the operator. Since the missile is relatively stable in flight and slow to respond to control, corrections must be substantial and timely. As a consequence, the probability of a first-round hit with this system

---

[42] S. Canby, *op. cit.*

[43] TRADOC Bulletin 2, *op. cit.*

tends to increase with range and peaks at about 2500 meters.[44] Thus, it may be expected that this missile will be deployed for engaging targets at ranges between 500 and 2500 meters. However, this particular system is considered to be obsolete and is not likely to be encountered in any significant numbers in future conflicts with Soviet forces.[45]

The *Sagger* system, like the *Snapper* system, is also based on a wire-guided control mechanism. It is more modern (fielded in the mid-1960s) and is smaller, lighter, and more flexible than the *Snapper* system. As discussed previously, it can be mounted on the *BMP* or the *BRDM* armored vehicles. It also comes in a "suitcase" version designed for employment by a single gunner in a concealed position.[46] To employ the *Sagger* missile, the gunner must visually track both the missile and the target and manually control the path of the missile to the target. Thus, unobstructed lines-of-sight are important for the effective employment of this system. The main problem in effectively using this system to kill opposing armored vehicles is "capturing" the missile and bringing it to bear on the target after it has been fired. For both the ground and vehicle versions of this system, the gunner can operate the system from a remote location: up to 15 meters in the ground version and up to 80 meters in the vehicle version. The further away the operator is from the firing position of the missile, the more difficult it is for him to capture the missile after it has been fired. Generally, under the best conditions, the fired missile can be captured at ranges from 500 to 800

---

[44]TRADOC Bulletin 1, *op. cit.*

[45]TRADOC Bulletin 2, *op. cit.*

[46]*Ibid.*

meters (about five to eight seconds after it has been fired). Under battlefield conditions, it is expected that most gunners will be able to engage opposing armored targets at ranges between 1000 and 3000 meters.[47]

The suitcase *Sagger* is usually employed by three-man crews equipped with four missiles. Two of the crew are *Sagger* gunners, while the third acts to protect the two gunners in a forward position using an *RPG-7*, a rocket-assisted grenade launcher. A typical layout for a *Sagger* crew is presented in Figure 6. This figure is taken from TRADOC Bulletin 2 (U)[48] and thus represents current US Army information concerning this weapon system.

The *Sagger* system is highly accurate and very lethal. For example, for ranges from 1000 to 3000 meters, the probability of a first-round *hit* against a stationary target is just under 90 percent.[49] For these same ranges, the probability of a first-round *kill* against a stationary, fully-exposed *M60A1* tank is just over 60 percent.[50] However, at short ranges the effectiveness of this system is somewhat degraded, particularly against moving targets. Further, against targets in hull defilade positions, its effectiveness is reduced by about 50 percent. Thus, in the future, the system will likely be deployed to maximize engagement at ranges between 1000 and 3000 meters where cover and concealment of the avenues of approach are minimal. Further, it is unlikely that *Sagger* will be deployed where the likelihood of short range (less than 1000 meters) engagement is high.

---

[47] *Ibid.*

[48] TRADOC Bulletin 2, *op. cit.*

[49] TRADOC Bulletin 1, *op. cit.*

[50] TRADOC Bulletin 2, *op. cit.*

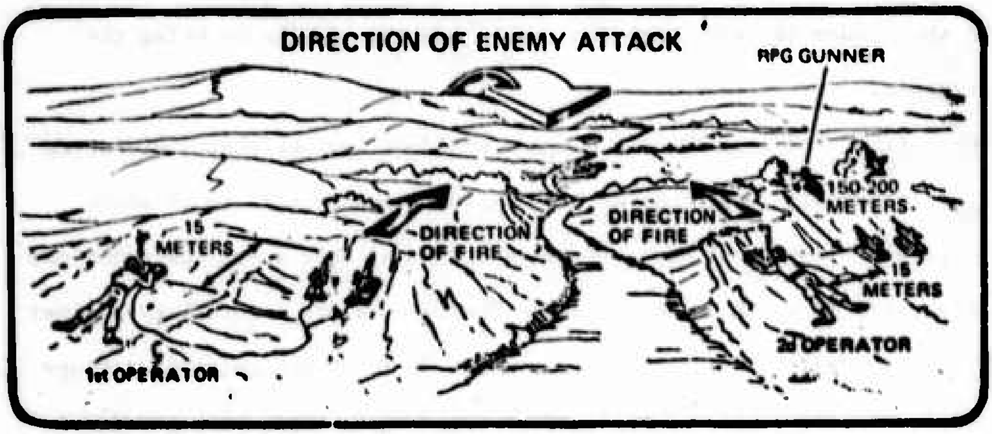


Figure 6. Typical deployment of a *Sagger* antitank guided missile team.[51]

[51]Reproduced from TRADOC Bulletin No. 2 (U), *Soviet ATGMs: Capabilities and Countermeasures*, Department of the Army, US Army Training and Doctrine Command, Fort Monroe, Virginia, April 1975.

Finally, the *Swatter* missile system is the most recent antitank guided missile system developed by the Soviets. Guidance commands are transmitted by radio rather than by wire. Three frequencies are available to reduce interference from electronic countermeasures. It is considered to be the most responsive and accurate of the Soviet antitank guided missile systems. It travels at higher velocities (about 137 meters per second), achieves longer ranges, and is easier to control than either the *Snapper* or *Sagger* systems.[52] Two versions are known to exist (*Swatter-A* and *Swatter-B*). It has been observed mounted on the *BRDM* reconnaissance vehicle and on an *Mi-24(Hind)* assault helicopter.[53] This system also requires the gunner to track both the target and the missile to bring the two together.

Once fired the missile does not arm until it reaches about 500 meters (i.e., after about 3.6 seconds). Its maximum range appears to be about 3500 meters.[54] While not much information is available about its empirical effectiveness, it is believed to have a first-round *hit* probability against a stationary *M60A1* tank target of about from 80 to 90 percent over a range out to 3500 meters. Some unconfirmed reports suggest that even greater ranges are possible with little or no degradation of effectiveness.[55] Thus, it may be expected that this missile system is likely to be deployed to engage targets at ranges between 500 and at least 3500 meters. Further,

---

[52]TRADOC Bulletin 1, *op. cit.*

[53]TRADOC Bulletin 2, *op. cit.*

[54]TRADOC Bulletin 1, *op. cit.*

[55]*Ibid.*

since it is visually guided by the operator and unobstructed lines-of-sight are necessary for its effective employment, it is likely that it will be used in areas that maximize the number of direct lines-of-sight between the missile and the operator. Obviously, obtaining many unobstructed lines-of-sight will be more of a problem when deployed in the ground mode than the air, since on the ground gross terrain features are more likely to be available for obstructing lines-of-sight.

In addition to these missile systems, Soviet ground forces are equipped with a relatively short range, high velocity (100 meters per second)[56] antitank rocket called the *RPG-7*. This weapon is designed for close-in defense. While it can fly as far as 900 meters, the hit probability for this weapon at 300 meters is only about 22 percent. At 500 meters this probability decreases to less than five percent. However, at ranges less than about 200 meters, the hit probabilities are quite high. For example, at ranges out to 100 meters, this probability is about 96 percent. At 200 meters it is about 51 percent. These data are based on a test situation involving a 7.5x15 foot [2.3x4.5 meter] panel moving at about nine miles per hour.[57] Similar results were obtained in tests involving a stationary frontal tank target of 2.3x2.3 meter dimensions.[58] Thus, it may be expected that this system will be encountered in situations involving

---

[56] T. Dawson. "Analysis of Rocket-Assist Aspects of Infantry Antitank Weapons," *Army Research and Development News Magazine*, November-December 1975, p 15.

[57] TRADOC Bulletin 1, *op. cit.*

[58] T. Dawson, *op. cit.*

short (less than 200 meters) target ranges, e.g., during the last stages of an assault by opposing forces on a Soviet position.

As discussed in the previous section, the *T-62* is one of the main battle tanks employed by Soviet ground forces in armored combat. It mounts a 115mm smoothbore tank cannon, which is extremely effective against opposing armored vehicles. For example, the first round *hit* probability of a *T-62* against a stationary M60A1 tank target at 100 meters is about 80 percent, while at 1500 meters it is 50 percent. The first-round *kill* probability for this same situation is just over 65 percent at 1000 meters and about 45 percent at 1500 meters. Against an M60A1 tank target approaching at a 30 degree angle at 12 miles [20 kilometers] per hour at 1000 meters, the first-round *hit* probability is about 75 percent, while at 1500 meters it drops to about 35 percent. For this situation, the first-round *kill* probability is just over 60 percent at 1000 meters and about 35 percent at 1500 meters.[59] In both cases, it is assumed that the *T-62* tank was firing APFDS ammunition. Thus, Soviet tanks are designed for fast first-hit probabilities at relatively long (1000 to 1500 meters) target-to-observer ranges.

In tank-to-tank combat, first-round hits are important since the tank that fires and hits first is usually the victor. For Soviet tank platoons (composed of three tanks), the technique of fire is for the platoon leader to direct the fire of his entire platoon on a particular target. After this target has been destroyed, the fire of the platoon is shifted to another target.[60] As a consequence of this capability to fight effec-

---

[59]TRADOC Bulletin 1, *op. cit.*

[60]*Ibid.*

tively at relatively long ranges, it is likely that Soviet tank platoons will seek to initiate engagements with US Army tank units at these ranges in a future conflict.

Another aspect of this long-range hit capability concerns the relative sizes of Soviet and US armored vehicles at long ranges, e.g., greater than 1000 meters. Table 3 presents the dimensions of selected US and Soviet army vehicles. In addition, it presents the vertical and horizontal visual angles subtended by each of these vehicles if they were viewed from the front at 1000 meters. Two observations are evident from inspection of this table. First, Soviet Army vehicles are generally smaller in all dimensions than their US Army counterparts. Second, the vertical and horizontal visual angles subtended by the Soviet vehicles tend to be two or three minutes smaller than the angles subtended by comparable US Army vehicles. For example, at 1000 meters, the Soviet *T-62* tank subtends a vertical visual angle of 7.5 minutes and is thus likely to be a very difficult target to acquire at this range. On the other hand, the *M60A1* subtends a vertical visual angle of approximately 11 minutes at a 1000-meter range and should be somewhat less difficult to acquire compared to the Soviet *T-62* tank at this range. As a consequence, a target presentation methodology should take these size differences into account, particularly if US armored equipment is employed to simulate Soviet armored equipment. This is particularly important since (as was noted above) future conflicts involving engagements between Soviet and US tanks are likely to occur over relatively large ranges.

Based on the information discussed in the above paragraphs, it is possible to assemble a composite picture of the range and hit capabilities

Table 3. Dimensions of and Visual Angles (@1000 Meters) Subtended by Soviet and US Army Vehicles[61]

Vehicle	Physical Dimensions (Meters) Height	Width	Length	Vertical Visual Angle @1000 Meters	Horizontal Visual Angle @1000 Meters
Soviet Army					
T-55 Tank	2.68	3.25	6.26	9.2'	11.2'
T-62 Tank	2.18	3.37	6.55	7.5'	11.6'
PT-76 Light Tank	2.23	3.14	6.85	7.7'	10.8'
BTR-60PB Combat Vehicle	2.29	2.81	7.31	7.9'	9.7'
BMP Combat Vehicle	1.85	3.10	6.51	6.4'	10.7'
BRDM Recon Vehicle	1.90	2.25	5.70	6.5'	7.7'
US Army					
M60A1 Tank	3.28	3.63	6.95	11.3'	12.5'
M60A2 Tank	3.20	3.63	6.95	11.0'	12.5'
M551 Light Tank	3.00	2.80	6.30	10.3'	9.6'
M113 APC	2.20	2.69	4.68	7.6'	9.2'
M114 APC	2.33	2.33	4.46	8.0'	8.0'
LVTP7 Landing Vehicle	3.14	3.20	7.93	10.8'	11.0'

[61] Based on data found in (R. Pretty and D. Archer, eds.) *Jane's Weapon Systems 1970-1971* (2nd ed.), New York: McGraw-Hill, 1970.

of Soviet antiarmor forces. For ranges out to about 200 meters, the *RPG-7* can hit targets (tank size) with a probability of at least 50 percent. For ranges out to 1500 meters, the *T-62* tank cannon can hit targets (tank size) also with a probability of at least 50 percent. For ranges between 500 and 3500 meters, the operational Soviet antitank guided missile systems have a hit probability of between 80 and 90 percent against tank-sized targets. Thus, these antiarmor systems fit together in a tactical system which is extremely effective at ranges out to about 3500 meters. The typical deployment of these weapon systems in a defensive posture reflects this capability (see Threat Battlefield Tasks/Techniques below).

Figure 7 presents the expected manner of deployment of the *Sagger* antiarmor systems discussed in this section for a hasty defense by a Soviet motorized rifle regiment equipped with *BMPs*. In this defense, it is assumed that the Soviet forces have not had time to lay in mines or dig trenches to provide protection for dismounted troops. This figure is based on information found in TRADOC Bulletin 2 (U),[62] and thus reflects the US Army's current information concerning Soviet doctrine in this respect.

Threat air defense weapon systems. Soviet forces have a complete air defense system that integrates the complementary capabilities of individual weapons, antiaircraft guns, and antiaircraft missiles to form a protective screen around and above their ground forces.[63] This air defense "umbrella" may extend as far as 50 kilometers beyond the initial

---

[62] TRADOC Bulletin 2, *op. cit.*

[63] TC 17-17, *op. cit.*

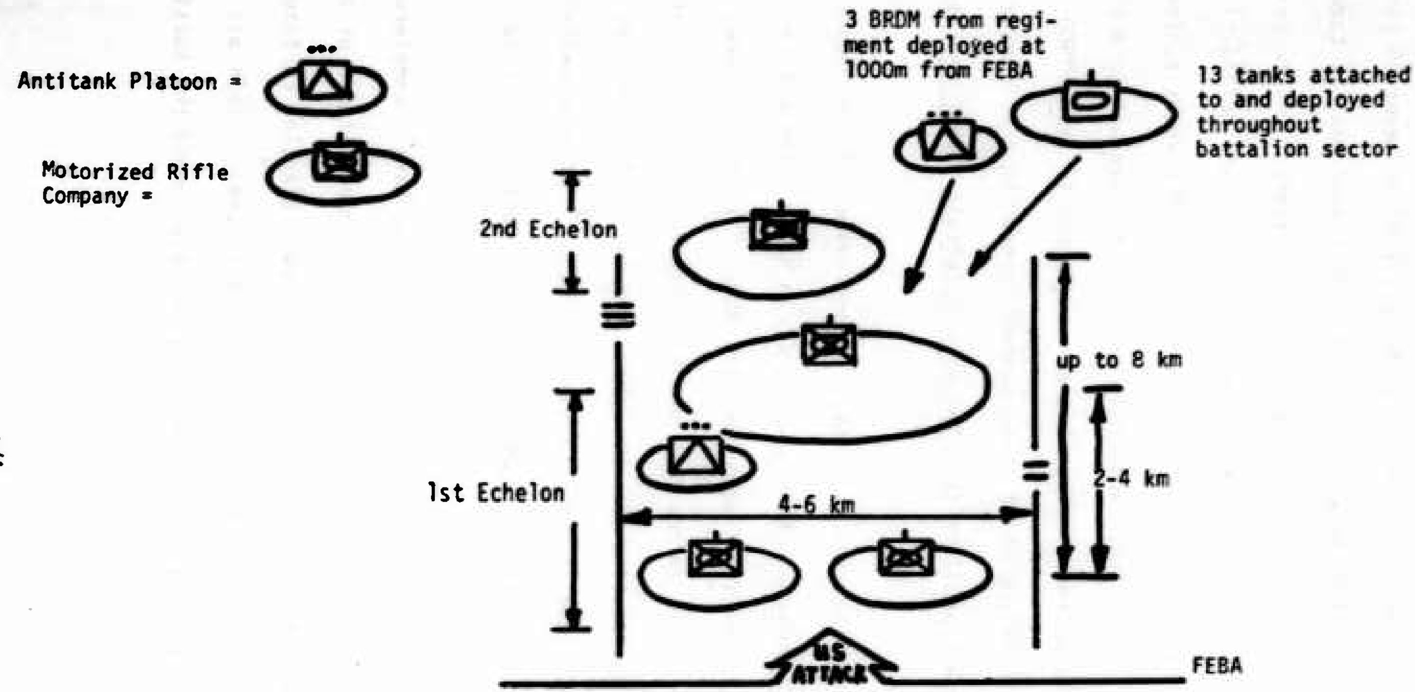


Figure 7. Typical deployment of *Sagger* equipped armored vehicles in a defensive posture by a threat motorized rifle battalion.[64]

[64] Based on information contained in TRADOC Bulletin 2 (U), *Soviet ATGMs: Capabilities and Countermeasures*, Department of the Army, US Army Training and Doctrine Command, Fort Monroe, Virginia, April 1975.

disposition of Soviet ground forces and in the air up to altitudes of 100,000 feet [30.5 kilometers]. The systems comprising this umbrella are generally limited to line-of-sight for target acquisition. For full advantage they must be deployed in relatively open terrain. Some components of the system have limited mobility. This tends to reduce the overall effectiveness of the umbrella when ground forces advance rapidly as they may "outrun" the less mobile elements of the air defense system.[65]

In general, opposing ground forces with their complementary air support (e.g., helicopters or high performance fixed-wing aircraft) which face the Soviet air defense umbrella can expect to be subjected to fire from the *SA-2*, the *SA-4*, and the *SA-6* guided missile systems first. Next, they can expect to encounter mobile antiaircraft guns such as the *ZSU-57-2* and towed systems like the *ZSU-23-2* twin antiaircraft cannon, the *ZSU-4* four barreled machinegun, and the *S-60* single barreled cannon Next, smaller guided missile systems such as the *SA-7* and the *SA-9* are likely to be encountered. Finally, at the level of individual soldier or armored combat vehicle, such weapons as 14.5mm and 12.7mm heavy machineguns, as well as automatic assault rifles, will be employed against incoming aircraft.[66] Figure 8 presents the protective envelopes provided by selected of these weapon systems schematically, and as well, their likely positions relative to an initial defense line.[67] Table 4 presents the data on which this figure is based. The following paragraphs briefly discuss these systems.

---

[65] TC 17-17, *op. cit.*

[66] FM 17-50, *op. cit.*

[67] *Ibid.*

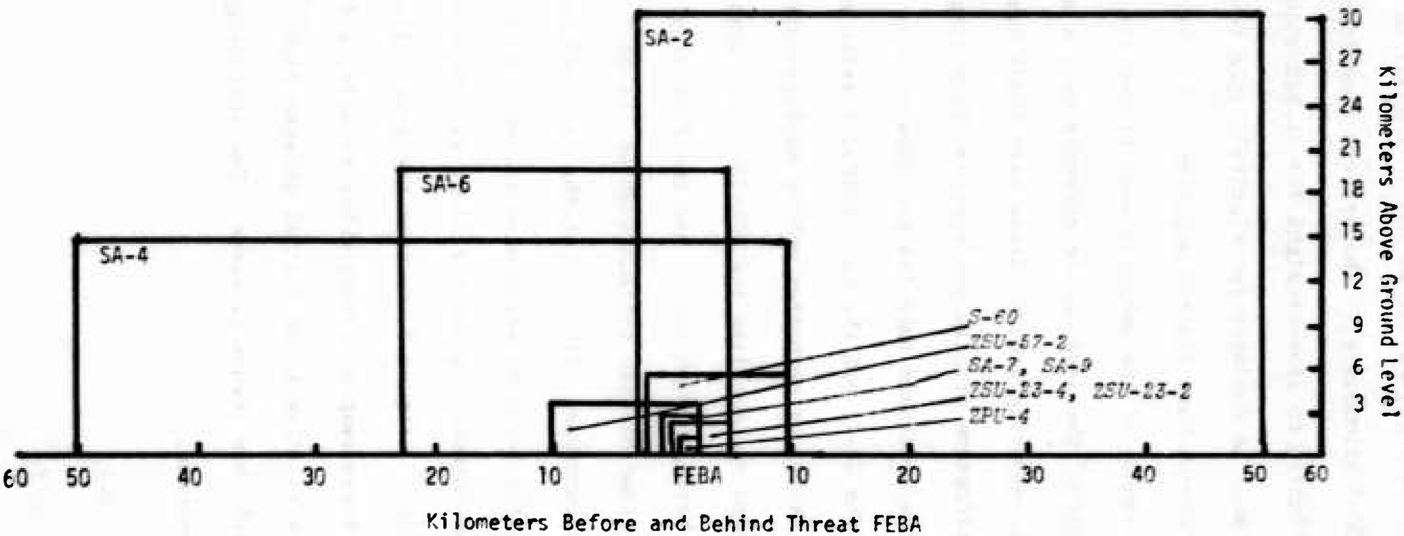


Figure 8. Schematic of threat air defense "umbrella" indicating the relative positions and kill zones of selected threat antiaircraft cannon, machinegun, and missile systems.[68]

---

68 Based on information contained in FM 17-50, *Attack Helicopter Operations* (Draft), October 1975, and TC 17-17, *Gunnery Training for Attack Helicopters* (Draft), 1 August 1975, Department of the Army, US Army Armor School.

Table 4. Ranges and Location Relative to the Threat FEBA for Selected Threat Antiaircraft Cannon, Machinegun, and Missile Systems

Antiaircraft System	FEBA Location	Lateral Range	Altitude
SA-2	50 km behind FEBA	53 km	0.15-30.5 km
SA-4	10 km behind FEBA	60 km	0.06-15.2 km
SA-6	5 km behind FEBA	37 km	0.06-20.1 km
SA-7	Frontline positions	2 km	3 km
SA-9	Frontline positions	2+ km	3+ km
ZSU-57-2	Frontline positions	12 km	4 km
ZSU-23-4	5 km behind FEBA	5 km	2.5 km
ZSU-23-2	Frontline positions to 100 km to rear of FEBA	5 km	2.5 km
ZPU-4	Frontline positions to 100 km rear of FEBA	1.4 km	1.4 km
S-60	10 km behind FEBA	12 km	5.8 km

The *SA-2 (Guideline)* system is composed of a battery of six single mobile missile launchers, a fire-control radar system, and a loader vehicle. This system fires surface-to-air missiles which are effective at altitudes of 500 to 100,000 feet [150 meters to 30.5 kilometers] out to approximately 53 kilometers from the launch site. Overall, it is judged to have limited mobility. It is usually deployed about 40 to 50 kilometers behind frontline Soviet positions.[69,70]

The *SA-4 (Ganef)* system is a low-altitude, surface-to-air guided missile system composed of three twin launchers, a fire-control radar vehicle, and a single loader vehicle. The twin launcher vehicles are tracked and capable of a 360-degree traverse. The other vehicles are also tracked. The missiles fired by this system are effective at altitudes from 200 to 50,000 feet [60 meters to 15.2 kilometers] out to approximately 60 kilometers. Overall, it has reasonably good mobility due to the fact that all vehicles in the battery are tracked. Usually, this system is deployed to 10 kilometers behind frontline positions.[71,72]

The *SA-6 (Gainful)* system is a low-altitude, surface-to-air guided missile system composed of three triple launcher vehicles, a fire-control radar, and a single loader vehicle. All vehicles in the battery are tracked. Further, the launcher vehicles (which use components of the *ZSU-23-4* chassis) have a 360-degree traverse capability. The missiles fired by the system are designed for use against low altitude targets (e.g., 200 to 400 feet [60 to 120 meters], but have a ceiling of 66,000

---

[69] TC 17-17, *op. cit.*

[70] FM 17-50, *op. cit.*

[71] TC 17-17, *op. cit.*

[72] FM 17-50, *op. cit.*

feet [20.1 kilometers]. Its maximum lateral range is about 37 kilometers. Usually, this system is deployed five to ten kilometers behind frontline positions.[73,74]

The *SA-7 (Grail)* system is a hand-held, low-altitude, surface-to-air system which is sighted optically by its gunner. It fires a heat-seeking missile similar to the US *Redeye* system. It has a maximum ceiling of 10,000 feet [3050 meters] and a lateral range of two kilometers. Usually it is deployed at the platoon level.[75,76]

The *SA-9 (Gaskin)* missile system is an improved version of the *SA-7*. However, it is longer and heavier with a more powerful warhead and a greater range, e.g., about five kilometers.[77] As a consequence, it is mounted on a vehicle (*BRDM*) and is fired from quadruple canister launchers. According to recent information, the *SA-9 (Gaskin)* system is currently replacing the low-altitude *SA-3 (GOA)* system which was designed to supplement the *SA-2* system's high-altitude capability.[78]

As discussed in the Threat Armor section of this chapter, the *ZSU-57-2* and *ZSU-23-4* armored antiaircraft systems are the main sources of air defense for motorized rifle and tank divisions. Usually, the *ZSU-57-2* is deployed in six vehicle batteries with forward ground maneuver elements. It has a tactical antiaircraft range of about four kilometers. The *ZSU-*

[73] TC 17-17, *op. cit.*

[74] FM 17-50, *op. cit.*

[75] TC 17-17, *op. cit.*

[76] FM 17-50, *op. cit.*

[77] R. Pretty, *op. cit.*

[78] *Ibid.*

23-4 is usually deployed with the *SA-6* missile battery to form a complementary interlock in the air defense screen. It has a tactical antiaircraft range of 2.5 kilometers without radar (i.e., optically) and 3.0 kilometers with radar.[79,80]

The *ZU-23-2* towed antiaircraft cannon is an optically-controlled system composed of twin 23mm cannons mounted on a towed carriage. It is usually deployed with frontline elements in depth to 100 kilometers in batteries of six weapons. It has a tactical antiaircraft range of 2.5 kilometers.[81,82]

The *ZPU-4* is an optically-controlled antiaircraft machinegun composed of four 14.5mm machineguns mounted on a four-wheeled towed carriage. It is usually found within motorized rifle units at the regimental level. It has a line-of-sight range of about 1.4 kilometers.[83,84]

The *S-60* is a single barreled 57mm cannon mounted on a four-wheeled towed carriage. This gun is typically used for air defense, but it can also be used against armored vehicles. It is usually deployed 10 kilometers to the rear of forward forces. It has a maximum ground range of approximately 12 kilometers and is effective in an antiaircraft mode up

---

[79]TC 17-17, *op. cit.*

[80]FM 17-50, *op. cit.*

[81]TC 17-17, *op. cit.*

[82]FM 17-50, *op. cit.*

[83]TC 17-17, *op. cit.*

[84]FM 17-50, *op. cit.*

to altitudes of six kilometers with off-carriage fire control. In addition, it can be traversed a full 360 degrees.[85,86]

The last line of defense in the Soviet air umbrella is the weapons of Soviet ground (maneuver) forces, e.g., vehicle-mounted machineguns, individual weapons, and the *SA-7 (Grail)* hand-held missile system. As indicated in the section discussing threat armor, many armored vehicles mount 12.7mm or 14.5mm heavy machineguns for air defense. The 12.7mm machinegun has an effective range out to about one kilometer, while the 14.5mm machinegun has an effective range of about 1.4 kilometers. Individual weapons (e.g., the 7.62mm AKM assault gun or the 7.62mm RKP squad automatic weapon) have effective ranges out to about 500 meters. Finally, as discussed above, the *SA-7 (Grail)* missile is effective out to about two kilometers up to altitudes of about 10,000 feet [3050 meters].[87]

It is evident from the number and deployment of the various systems which comprise the Soviet air umbrella that they emphasize attainment and retention of tactical air supremacy over the battlefield. Armored antiaircraft systems (e.g., *ZSU-23-4*) organic to motorized rifle and tank divisions may be found as far forward as leading tank elements. Forward combat elements have the capability for air defense using both heavy machineguns and the *SA-7 (Grail)* missile system. In the 1973 Arab-Israeli War, such an umbrella proved to be quite effective in denying the Israeli Air Force the use of the battlefield air space. For example, due to the Soviet-type air defense umbrella established by the Egyptians and Syrians at the Suez Canal and in the Golan Heights, respectively, the

---

[85] TC 17-17, *op. cit.*

[86] FM 17-50, *op. cit.*

[87] *Ibid.*

Israeli Air Force was initially kept from making strikes within the Egyptain or Syrian interior. In addition, the Israeli Air Force was able to provide only the most limited close-air support to the Israeli ground forces in the area where the unbrella was located.[88] Thus, the targets provided by the components of this umbrella (particularly those in the forward areas of the Soviet defensive zone) are exceedingly important with respect to the modern battlefield.

Threat artillery. Prior to 1968, it was argued that NATO and Warsaw Pact forces were roughly equal in artillery and mortar tubes. However, it was pointed out that, in fact, the Soviets had the advantage in artillery tubes and saturation multiple rocket launchers. NATO forces, on the other hand, had an advantage in infantry light mortars. Since that time the situation has changed to favor the Soviets. During this period of time they have significantly strengthened their artillery capability (by increasing the number of artillery tubes) and increased the number and caliber of their mortars. Now, Soviet divisions average approximately the same number of artillery tubes as equivalent American division, even though they are numerically smaller than American divisions. The Soviet divisions now present in East Germany have about as many artillery tubes as US forces and other NATO forces, division for division. Because of the large number of Warsaw Pact divisions, it is thus estimated that they now have more artillery capability than their NATO counterparts.[89]

---

[88] A. Farrar-Hockley. "II. The October War," in E. Monroe and A. Farrar-Hockley, *The Arab-Israeli War, October 1973, Background and Events*, Adelphi Papers, No. 111, The International Institute of Strategic Studies, London, England, Winter 74/75, pp 14-31.

[89] S. Canby, *op. cit.*

As is true with US forces, the principal means of fire support for Soviet advancing ground forces is artillery. Soviet doctrine in stressing the offensive breakthrough for advancing ground forces specifies that leading maneuver forces should be supported by artillery densities of 70-100 tubes per kilometer of front.[90] Further, it is expected that this artillery will fire at high rates for relatively long periods of time, e.g., 20 to 40 minutes.[91] Thus, artillery is also an important component of Soviet forces and are targets of definite importance.

The most common forms of Soviet artillery are: (a) the 120mm mortar with a range of 5.0 to 5.7 kilometers, (b) the 122mm towed howitzer with a range of 15.3 kilometers, (c) the 152mm towed howitzer with a range of 17.3 kilometers, (d) the truck-mounted rocket launcher with a range of 20.5 kilometers, and (e) the 122mm and 152mm self-propelled guns. Not much is known currently about these two latter weapons with respect to their effective range. Both are mounted on tracked vehicles,[92,93] and are thus highly mobile.

According to TC 7-24,[94] the typical Soviet motorized rifle and tank divisions each have an attached artillery regiment with a total of 54 152mm and 122mm howitzers. Assuming six howitzers per battery, there are nine batteries per artillery regiment. These batteries operate at the division level to provide indirect fire support for advancing division ground forces. In addition, each Soviet motorized rifle regiment

---

[90]TRADOC Bulletin 8, *op. cit.*

[91]D. Daignault. "The Threat," *Armor*, November-December 1975, 85(6), 37-38.

[92]TC 17-17, *op. cit.*

[93]FM 17-50, *op. cit.*

[94]TC 7-24, *op. cit.*

has an organic six-howitzer artillery battery (usually 122mm howitzers) which provides artillery support at the regimental level. Finally, within the artillery regiments attached to motorized rifle and tank divisions, there are three batteries of multiple-barreled rocket launchers with six launchers per battery. These are also located within the operational area of the division to the rear of advancing or defending division ground forces.

For all practical purposes, only relatively few indirect fire artillery systems such as howitzers are likely to be encountered in the frontline battle area, except during periods of rapid breakthrough. During these times, it can be expected that a significant number of indirect fire artillery will be brought into the main battle area so that they are within range of and can bring heavy concentrations of fire on enemy rear areas.

On the other hand, the 120mm mortar is found at the battalion level. According to TC 7-24,[95] each Soviet motorized rifle battalion has attached to it one mortar platoon composed of one officer, 35 enlisted men, and six 120mm mortars. Generally, these weapons are deployed with the second echelon defense forces in both the deliberate and hasty defense situations in two groups of three mortars each. An example of their deployment in a deliberate defense is shown in Figure 14.

Threat Mobility and Airborne Capability

Currently, Soviet forces do not place as great an emphasis on the use of helicopters to achieve mobility as US ground forces. This is evident from Figure 9, which shows the number of various types of military equipment per thousand men for both US and Soviet land forces world wide.

---

[95] *Ibid.*

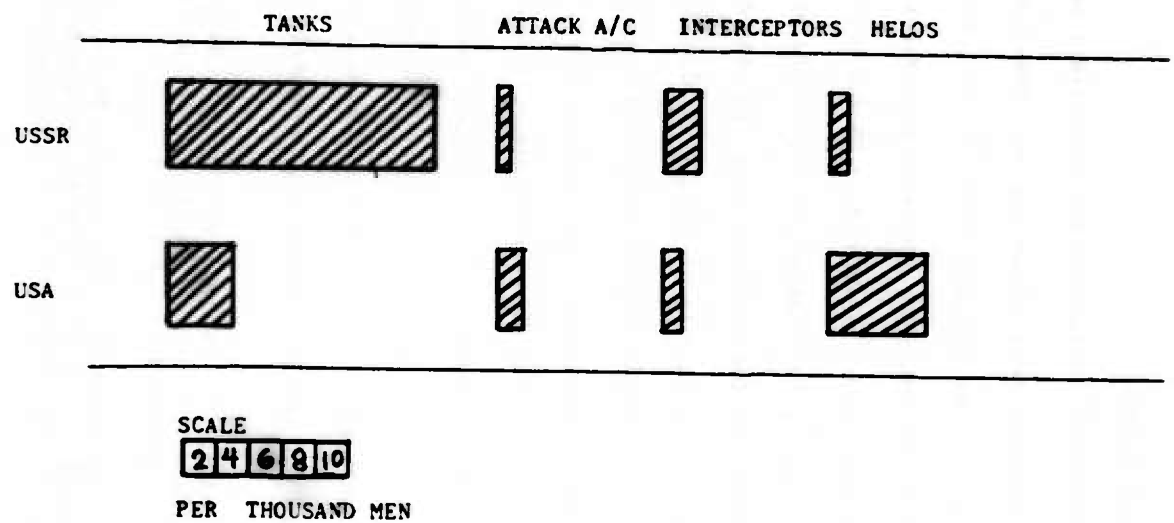


Figure 9. Number of tanks and aircraft in USSR and USA inventories per thousand men.[96]

[96] N. Augustine. "Operations Research and the Next War," *Army Research and Development News Magazine*, November-December 1975, p. 23, adapted from Figure 2.

From this figure it is clear that the Soviets have placed their emphasis on a tank force, while US forces have placed their emphasis on a tank/ helicopter force. However, this is not to deny the existence and use of the helicopter by Soviet ground forces.

The Military Balance 1974-1975[97] estimates that the Soviets employ at least 2500 helicopters to support their ground forces. These are organized into regiments attached to tactical air armies.[98] In a military conflict, at least one tactical air army with its helicopter resources would be assigned to a Soviet Army Group (similar to a US Army Group) for use by the commander as required.[99] The helicopters that could be expected to be available for deployment by the commander are: (a) the *Mi-6 (Hook)*, an air transport helicopter capable of lifting an ASU-85 airborne assault gun (a tracked, turretless armored vehicle with an 85mm main gun) and 65 combat-equipped infantrymen, (b) the *Mi-8 (Hip)*, an air transport helicopter capable of carrying 24 combat-equipped infantrymen, (c) the *Mi-10 (Harke)* and the *Mi-12 (Homer)*, large transport helicopters designed to carry loads of 15 and 27 tons, respectively,[100] and (d) the *Mi-24 (Hind)*, a true attack helicopter, is equipped with a machinegun in the nose, rocket pods and (in one model) antitank guided missile launchers

---

[97] "Countries and Principal Pacts: The United States and the Soviet Union," in *The Military Balance 1974-1975*, The International Institute for Strategic Studies, London, England, 1974, pp 3-10.

[98] A tactical air army is one component of a Soviet Army Group. Each air army is composed of regiments of transport aircraft, helicopter, and close-air support required for the operations of a Soviet Army Group during combat operations.

[99] G. Turviville. "A Soviet View of Heliborne Assault Operations," *Military Review*, October 1975, 55(10), 3-15.

[100] *Ibid.*

attached one to each wing.[101,102] This latter aircraft can also carry a crew of 12 combat-equipped infantrymen. It is expected that the *Mi-24 (Hind)* helicopter will be employed not only in heliborne landing operations, but also in support of motorized rifle and tank forces.

The primary role the Soviets currently assign to helicopters is the transport of forces into the enemy's rear to accomplish a variety of tasks. Examples of these tasks are:

a. to delay and destroy the enemy's reserve forces,

b. to capture and destroy enemy tactical nuclear weapons,

c. to occupy and hold strategic terrain areas, including water crossings, mountain passes, gorges, road intersections, etc.,

d. to capture and destroy rear command posts,

e. to seize and secure sections of a coastline in preparation for amphibious landings by marine elements.[103]

Although US forces spend quite a bit of time preparing for combat operations involving helicopters, Soviet forces believe that helicopter assaults can be planned and launched in a matter of hours. Based on the results of recent Soviet field exercises, this appears to be feasible.[104] Nearly all large scale Soviet and Warsaw Pact forces exercises have involved helicopter-delivered assault forces. These exercises have not only included the delivery of troops, but also helicopters operating in a fire-support role. Further, in these exercises there has been an emphasis on employing helicopters against armor. Thus, it is clear that

---

[101] TC 17-17, *op. cit*

[102] FM 17-50, *op. cit.*

[103] G. Turviville, *op. cit.*

[104] *Ibid.*

the Soviets and their allies are likely to employ the attack helicopter to some extent in future military conflicts involving their ground forces.[105]

However, as indicated above, the Soviets (as of the 1974-75 time frame) had only 2500 helicopters in their inventory, compared to the 10,000 helicopters in the US inventory.[106] Further, in this same time frame they had over 12,400 main battle tanks.[107] Thus, within the overall composition of Soviet forces, helicopters represent (at best) only a small fraction of the military equipment likely to be encountered on a future battlefield. As a consequence, it can be expected that as long as the Soviets employ a small number of helicopters in their army, these aircraft are likely to be seen only on an infrequent basis in a future battlefield situation.

Threat Battlefield Tactics/Techniques

The Soviets and their associated forces have opted for rapid offensive operations in order to prevent the mobilization of the potentially greater manpower of NATO forces in Europe. Their strategy may be best characterized in the following manner: a quick and overwhelming offensive developed from resources specifically designed for armored warfare (in both a mid- and high-intensity combat environment) and rapid deployment. Soviet doctrine stresses offensive tactics. As a result, manpower commitments will peak early during a conflict. Their strategy also includes attacks in the enemy's rear areas to destroy his capacity to

---

105 *Ibid.*

106 "Countries and Principal Pacts: The United States and the Soviet Union," *op. cit.*

107 *Ibid.*

continue. It is the purpose of this section of the report to discuss the Soviet concept of warfare in some detail with respect to both the defense and the offense.[108]

At the operational (conceptual) level, the Soviets have adopted and improved the German *blitzkrieg* concept, while at the tactical (implementation) level they have continued to emphasize the mass attack. The *blitzkrieg* concept of warfare holds that an opponent may be overwhelmed quickly by concentrating one's offensive forces on specific narrow sectors of the battle front, breaking through these sectors, moving to the enemy's rear, and enveloping his forces and paralyzing any further action on the part of the enemy. If few breakthroughs are required, or if opposing forces are relatively weak and lack depth, such tactics can lead to the successful conclusion of a campaign in a matter or days or weeks (e.g., Poland in 1939). For stronger defenses, more breakthroughs and additional offensive personnel and equipment are required.[109] Thus, there is also the emphasis on mass, i.e., the massing of men and equipment via armored mobility in continuous waves until the enemy's resources are exhausted.

More specifically, Soviet forces base their operations on the following tactical principles: the objective, the offensive, and mass.[110] For Soviet ground forces, the objective is the most important aspect of an operation. Attainment of the objective takes precedence over all else. As a consequence, high losses (e.g., 60 to 70 percent) are accepted by

---

[108] S. Canby, *op. cit.*

[109] *Ibid.*

[110] D. Daignault, *op. cit.*

these forces. Further, it is SOP for these forces to bypass all significant resistance, rather than to engage, so that the momentum of movement toward the objective will not be lost.

It is doctrine for Soviet forces to move 35-50 kilometers every 24 hours in a mid-intensity conflict and about 100 kilometers per 24 hours in a high-intensity conflict. Utilizing the ground mobility afforded them by their tanks and armored combat vehicles, they plan to maintain speed and place continuous pressure on opposing forces. Offense rather than defense is the basis of all their strategy.

Recognizing that it is not always possible to bypass an enemy force, Soviet ground elements emphasize penetration tactics to break through enemy forces in order to move to these forces' rear. Also, Soviet ground forces are trained for a 24-hour battle day. All of their vehicles carry night vision devices. As a result, Soviet forces can keep continuous pressure on opposing forces employing masses of personnel. This employment of masses of men and equipment is the third principle emphasized by Soviet forces. One consequence of the employment of this principle is that Soviet forces can sustain high losses, if necessary. More importantly, by massing large groups of men at the breakthrough area, an opposing force cannot possibly contain a breakthrough without resorting to employing the same tactic or employing nuclear weapons (with the possibility of adversely affecting its own troops in the area).

From this discussion, it is clear that Soviet doctrine is based on the belief that a decisive victory can be achieved only by offensive action supported by massive numbers of highly mobile troops and equipment who have the capability of rapid movement. In addition, the Soviets believe that the coordinated employment of combined arms is essential for success.[111] Thus, motorized rifle units can seldom be expected to operate without support from rear area artillery, antitank armor, and engineering elements. Further, as is evident from the discussion concerning air defense, Soviet forces employ large numbers of mobile and semi-mobile air defense systems to protect their troops from opposing high performance aircraft and helicopter weapon platforms.

Given that the typical combat operations likely to be initiated by Soviet ground forces on future battlefields will be offensive operations, it is important to have some understanding of the organization and actions Soviet forces are likely to take in these situations.

Threat forces attack in mass using an echelon formation, i.e., a formation in which subdivisions (divisions, regiments, battalions or companies) are placed behind one another at varying distances depending on the tactical situation. For example, an attacking motorized rifle regiment is usually organized into two echelons. The first echelon (composed of two motorized rifle battalions and elements of a tank battalion) initiate the attack and have the primary mission of defeating the enemy. The second echelon (usually composed of a motorized rifle battalion) follows the route of advance of the first echelon forces and has the secondary/followup mission which may change as the tactical situation develops. In particular, its main purposes are to provide for maintaining a high tempo of advance, to repel enemy counterattacks, and to exploit offensive successes of the first echelon. The march formation, direction of attack, and area of commitment are designed to provide direct support

---

111 S. Lovasz. "Soviet Motorized Rifle Company," *Infantry*, November-December 1975, 65(6), 30-35.

to the attack of the first echelon forces. In addition to the first and second echelon forces discussed above, there are usually relatively small reserve forces. At the regimental level these may be composed of one or two motorized rifle companies and are generally heavy in tanks.

It is typical for threat forces during an attack to try to achieve at least a three-to-one advantage in both personnel and weapon systems. They attempt to penetrate forward positions and seize deep objectives somewhat separated from each other. Following the successful seizure of their objectives, these forces move on to new objectives. According to TC 7-24,[112] it is generally expected that an attack by a motorized rifle regiment will be conducted in the following manner:

a. Prior to the attack, single or paired visual reconnaissance aircraft sorties will be flown to obtain information about the location of enemy positions and strength. These will be high performance aircraft at low altitudes.

b. Armored reconnaissance elements (two combat vehicles, *PT-76* or *BRDM)* will be seen moving with a lateral separation of about 100 meters toward the enemy position. Following these vehicles at a range of about one kilometer, three *BMPs* will be seen also moving toward the enemy position. Their area of responsibility will be across a front of about 1.5 kilometers wide.

c. To the left and right about 1.5 kilometers, the situation described in (a) and (b) above will be replicated.

d. Assuming that no unguarded routes are located by the reconnaissance elements, a probing attack will be initiated. This will be

---

[112]TC 7-24, *op. cit.*

likely accomplished by six *BMPs* and four *T-62s* moving toward the enemy position. These vehicles will take maximum advantage of cover. The area covered by these vehicles will approximate a rectangle 400 meters wide by 200 meters deep. The *T-62s* will normally take up positions about 100 meters in front of the *BMPs*. Both the tanks and the *BMPs* will keep a lateral separation of about 100 meters. The *BMPs* will usually move in pairs.

e. Assuming that the probing attack fails, the quick attack may be expected next. Usually, this will be implemented within one hour of the probing attack. It can be expected to take place across an area about two kilometers wide. This attack will likely be conducted by 12 *T-62* tanks and 30 *BMPs*. It typically commences with artillery preparation consisting of about 2000 rounds of high explosive as well as nonpersistent chemical and smoke rounds. After about 20 minutes, the advancing tanks and *BMPs* will be seen. The initial deployment of these units at about four to six kilometers from the opposing force's frontline is depicted in Figure 10. At this point the tanks and *BMPs* will be in column formation. At about one to three kilometers from the enemy's frontline position, these vehicles will deploy as depicted in Figure 11 into platoon columns. At about two kilometers or less, the actual assault begins with tanks firing on the move. Finally, at about one kilometer or less from the enemy's frontline position, these forces will deploy into the battle formation depicted in Figure 12.

f. Assuming that the quick attack fails, the leading elements of the tank and motorized infantry force that conducted this attack will prepare a hasty defense near the opposing force's frontline. Next, after

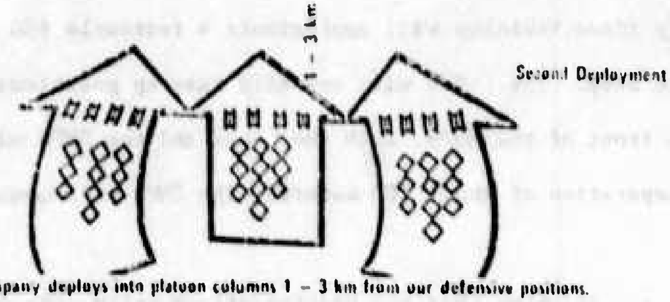


Figure 10. Initial deployment of a threat motorized rifle battalion at about 4 to 6 kilometers from the FEBA.[113]

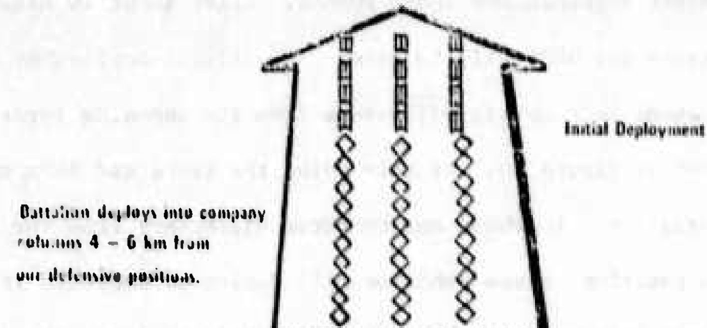
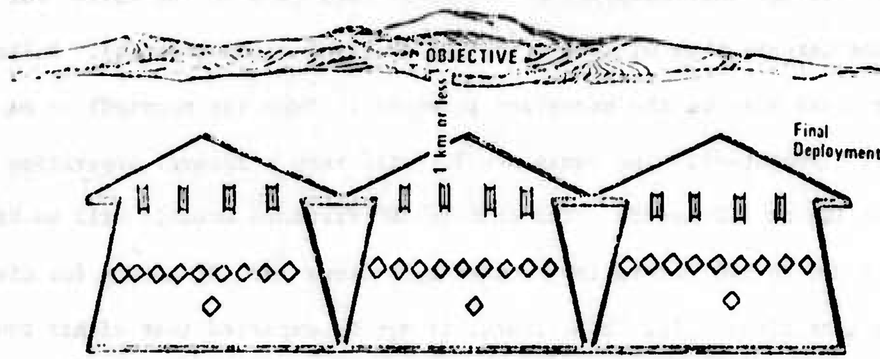


Figure 11. Deployment of a threat motorized rifle battalion at about 1 to 3 kilometers from the FEBA.[114]

---

113 Reproduced from TC 7-24, *Antiarmor Tactics and Techniques*, Department of the Army, US Army Infantry School, Fort Benning, Georgia, 30 September 1975.

114 *Ibid.*



Battalion normally attempts to deploy into battle formation 1 km or less from our position. Maintaining movement in columns increases speed of advance. Assault begins at 2 km or less depending on terrain.

Figure 12. Battle formation of threat motorized rifle battalion at about 1 kilometer or less from the FEBA.[115]

---

[115] Reproduced from TC 7-24, *Antiarmor Tactics and Techniques*, Department of the Army, US Army Infantry School, 30 September 1975.

reconnaissance has located important targets and engineering support has cleared lanes through enemy obstacles, a 15 to 30 minute artillery barrage will be directed against the opposing force's frontline position and critical targets located by the reconnaissance. The leading elements of the Soviet assault force will move to within 100 meters of the impact of the artillery fire. Next, after this fire has been shifted to targets away from the opposing force's frontline toward their rear, the assault will be commenced.

g. The main assault will be launched by second-echelon forces and be covered by the forces already in contact. Tanks will lead the assault, firing their machineguns and their main guns on the move. For important targets they will halt to fire (four to eight seconds). Following the tanks will be the motorized infantry in *BMPs* (if mounted) or on foot (if dismounted). The tanks usually will keep a lateral separation of about 100 to 150 meters. The tank-to-*BMP* distance usually will be kept to about 300 to 500 meters for mounted operations and 100 meters for dismounted operations. For this attack, it may be expected that either two or three reinforced motorized rifle companies will constitute the main force of the attack. In addition, there will likely be an antitank reserve, and engineer section, and a mortar platoon. These latter forces will be positioned initially in an area behind the advancing forces about four kilometers deep.

Deliberate attacks, such as the one described in the previous paragraph, are usually conducted at night. Quick attacks are more common during the day. The principles employed for the attack at night are basically the same as applied for the day attack. The following exceptions may be noted:

a. At night, the infantry (dismounted) will more often lead the attack. However, having night vision capability, armor will sometimes lead the attack.

b. The divisional second echelon will normally wait until daylight to pass through the first echelon to continue an attack.

c. Maneuver is kept simple, following terrain and road networks.

d. Column formations are more likely to be employed at night for conducting movement.

e. Less use of artillery preparation may be expected so that the element of surprise may be employed against the enemy.[116]

As discussed above, Soviet forces stress the offense as the primary combat operation. However, it is recognized by these forces that a tactical defense will on occasion be necessary. Soviet doctrine indicates that a defensive position would be taken up under the following conditions:

a. to economize forces in one area to free forces for another area,

b. to gain time,

c. to destroy attacking forces,

d. to provide cover for other forces in the process of withdrawal.[117]

Soviet forces deploy into two types of defensive postures: a hasty defense and a deliberate defense. The hasty defense is assumed when an attack has become stalled temporarily. The deliberate defense is assumed when a decision is made to halt an advance for more than a few hours.

---

[116]TC 7-24, *op. cit.*

[117]*Ibid.*

The basic differences between the two types of defense are with respect to the width of the defense, the location of supporting tanks, the amount of construction required, the complexity of antiarmor and artillery fire plans, and the depth of the security zone forward of the defensive frontline. The following paragraphs will discuss both of these defenses in some detail with respect to the above areas of differences for a motorized rifle battalion. This information is based on material contained in TC 7-24[118] and FM 17-50.[119]

In the deliberate defense, Soviet ground forces deploy in three basic zones: the security zone, the forward zone, and the main defense zone. The security zone extends from the front of the main position to about 16 kilometers forward of this position. In front of this zone there are usually reconnaissance troops in armored vehicles (*PT-76, BRDMs*) scouting for approach routes, headquarters, and tanks. Under pressure they pull back to the main position where they cover gaps, watch flanks, and secure the rear of this position. The security zone is manned by elements of the motorized rifle division's second echelon. They are placed in positions on the most important axes of advance. These troops are organized into reinforced platoon or company sized strongpoints.

At the rear of the security zone are the forward positions which are established at points up to five kilometers in front of the main defense position. These are manned by reinforced platoon and company sized units. They correspond in relative position to the strongpoints of the main defense. Finally, at a distance of from 500 to 1000 meters from the frontline defense position, battle outposts will often be found when

---

[118] *Ibid.*

[119] FM 17-50, *op. cit.*

forward positions have not been established. These are manned at the platoon level of strength. Figure 13 presents this information schematically, indicating the relative positions of the forces in the security zone and back toward the main defense line.

Figure 14 presents the typical layout for a Soviet main defense zone. This figure presents the situation for a battalion deployed along a 5000 meter frontage and to a 4000 meter depth. This area is organized into two echelons and has three basic lines of defense. The first echelon consists of two reinforced companies deployed into platoon sized strongpoints such that two lines of defense are presented. The second echelon is formed by the third company spread across the defense sector at about 1000 meters behind the second defense line. In addition to these personnel, the following regimental elements are often deployed within this defensive zone: a medium tank company, a 120mm mortar company, antitank guided missile sections, and air defense artillery elements.

Figure 15 presents the typical deployment for a Soviet motorized rifle battalion in a hasty defense. In this situation, the battalion has pulled off its approach route, taken up defensive positions, and is awaiting orders for further defensive action. In this situation the width of the defensive front is about 3000 to 5000 meters wide. Tanks are located to the rear of the defensive zone. There is little construction or trenches or laying of mines. Fire plans for antiarmor and artillery are kept very simple. The security does not extend forward very far and is not well defended.

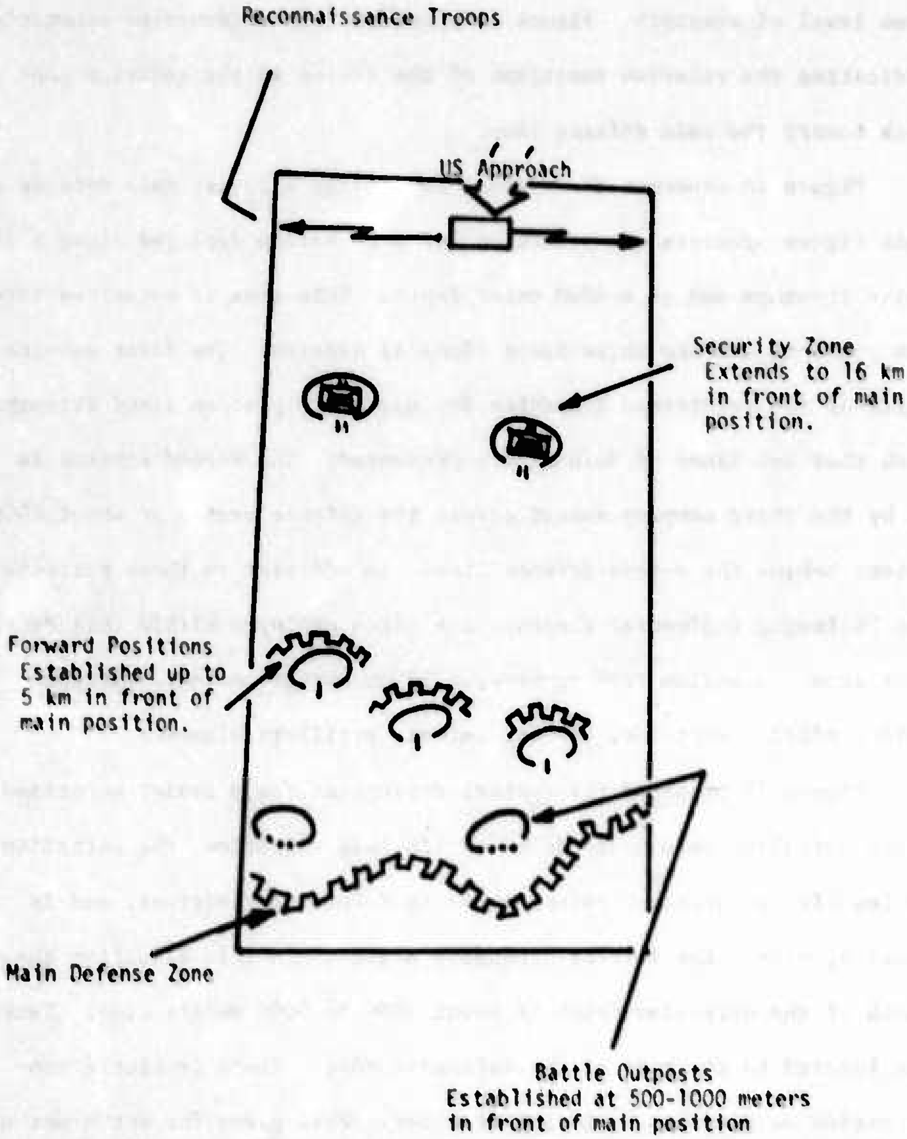


Figure 13. Typical deployment of a threat motorized rifle battalion unit in the security and forward defensive zones.[120]

---

[120]Based on material in TC 7-24, *Antiarmor Tactics and Techniques*, Department of the Army, US Army Infantry School, Fort Benning, Georgia, 30 September 1975.

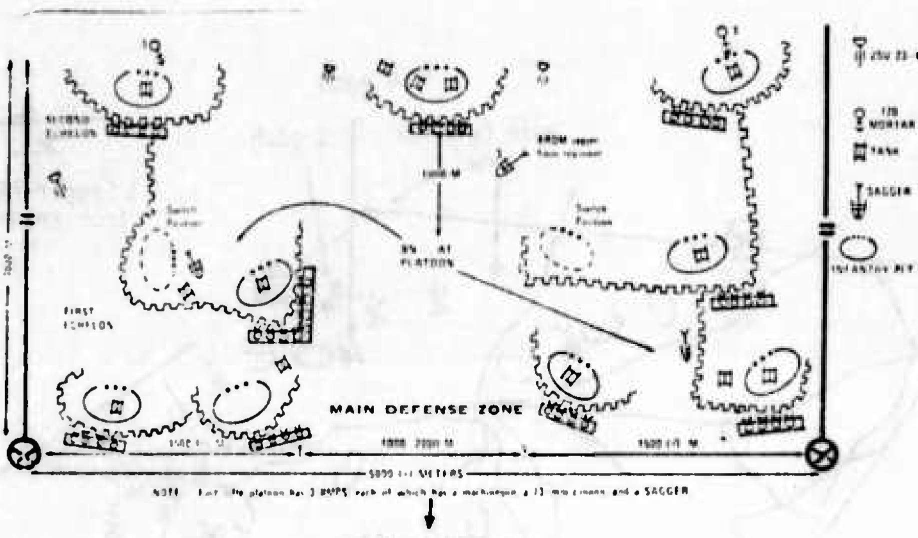


Figure 14. Typical deployment of threat motorized rifle battalion units in the main defensive zone.[121]

---

[121] Reproduced from TC 7-24, *Antiarmor Tactics and Techniques*, Department of the Army, US Army Infantry School, 30 September 1975.

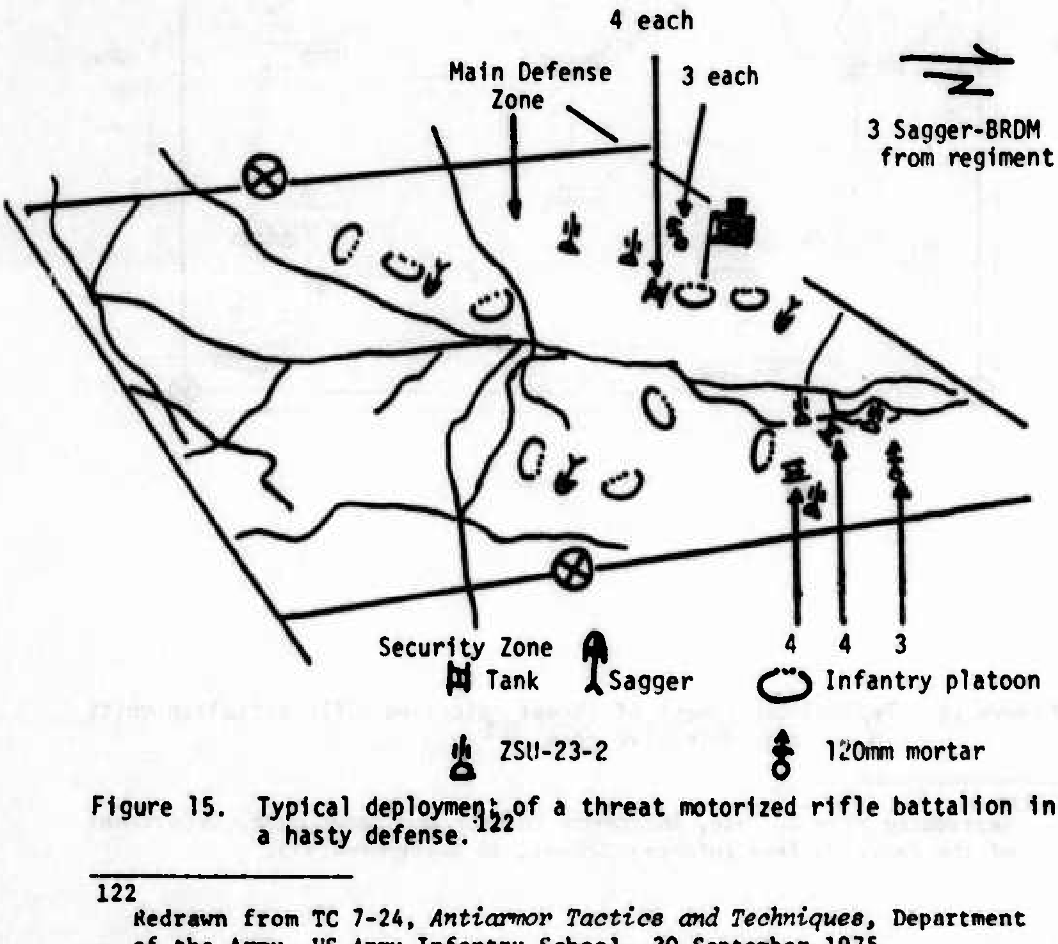


Figure 15. Typical deployment of a threat motorized rifle battalion in a hasty defense.[122]

122
Redrawn from TC 7-24, *Antiarmor Tactics and Techniques*, Department of the Army, US Army Infantry School, 30 September 1975.

Threat Tactical Nuclear Capabilities

Soviet ground forces are both structured and prepared for the employment of tactical nuclear weapons[123] during the course of a conflict with a major military power.[124] In particular, their organization of field forces, much of their military equipment, and their tactics are designed for the possible employment of tactical nuclear weapons. For example, their ground units are organized for mobility, which means that the effects of an eminent tactical nuclear strike may be reduced by rapid dispersal. Further, Soviet units are smaller than comparable US ground units (18 battalions per 12,000 men motorized rifle division *versus* 12 battalions per 16,000 men US motorized infantry division) and, thus, potentially less of a field target. As discussed above, much of the Soviet army is mounted in armored combat vehicles, which not only increases its mobility, but also provides protection against blast effects and radiation from nuclear weapons. Finally, in combat, a linear shock tactic designed to hug close to the enemy is employed, which is more difficult to target compared to the US deployment tactic of "two up and one back." Further, Soviet ground forces train extensively under simulated nuclear conditions.[125] Thus, they are presumably familiar with many of the problems a tactical nuclear strike may cause in such areas as command and control and communications. For these reasons then it may

---

[123] Tactical nuclear weapons are nuclear munitions designed for use against targets within a battlefield area or against targets directly connected with the maneuver of combatants forces. Included in this class of munitions are nuclear missile, nuclear artillery rounds, and nuclear mines.

[124] S. Canby, *op. cit.*

[125] *Ibid.*

be expected in a future conflict with the Soviet/Warsaw Pact forces in Europe that tactical nuclear weapons could be employed by these forces.

The Military Balance 1974-1975 provides some information about the number of and means of delivery of Soviet tactical nuclear weapons. It estimates that there are about 3500 nuclear warheads in the Soviet inventory. It is thought that the yield of these weapons is somewhat higher than similar NATO weapons which are in the low kiloton range.[126] The bulk of the delivery means for these weapons are ground-to-ground missile systems such as the *Frog, Scud, Shaddock,* and *Scaleboard* which collectively have ranges up to about 500 miles [800 kilometers]. In addition, tactical aircraft such as the *MiG-21 (Fishbed)* and the *SU-7 (Fitter)* appear to be capable of delivering these weapons. Finally, there is a 203mm cannon which can fire tactical nuclear tipped rounds.[127]

Little is known about the exact conditions under which the Soviets and their allies would employ tactical nuclear weapons on the battlefield. According to Heisenberg,[128] Warsaw Pact forces train under a scenario that assumes an American strategic first strike, followed by a Soviet strategic strike and a full nuclear offensive in Europe. Heisenberg notes that since the mid-1960s there have been indications in the Soviet military literature that a war in Europe might be fought without such weapons. However, he points out there appears to be no Soviet theory of limited nuclear weapons.

---

[126] "The Theatre Balance Between NATO and the Warsaw Pact," *op. cit.*

[127] W. Heisenberg. *The Alliance and Europe: Part I: Crisis Stability in Europe and Theatre Nuclear Weapons,* Adelphi Papers No. 96, The International Institute for Strategic Studies, London, England.

[128] *Ibid.*

Recently, though, Savkin[129] has discussed the problem of nuclear weapons on the battlefield largely from the Soviet point of view. His discussion indicates the following principles of employment of tactical nuclear weapons by Soviet forces:

a. Areas near deployed Soviet ground troops will be captured by these troops with important targets in more distant but adjacent areas being destroyed by tactical nuclear weapons.

b. Prior to an attack by ground troops, critical targets to the depth of the enemy's deployment will be destroyed with tactical nuclear weapons.

c. Nuclear barriers (zones of radioactive contamination) along specified avenues of approach will be established to prevent the enemy from sending reserves along these approaches.

d. Nuclear strikes will be followed-up with penetrations of tank and mounted infantry who are protected in their combat vehicles from the immediate dangers of the radioactivity in the area. In addition, airborne parties will be landed or dropped into areas attacked with these weapons immediately after the strike to destroy resistance of enemy troops which remain active.

e. The wide surprise employment of nuclear weapons will be a significant characteristic of future operations and battles. In particular, it will be the goal of attacking forces to employ these weapons against important targets unexpectedly at any time.

f. Enemy forces which possess nuclear capability (on the ground and in the air) will be prime targets for Soviet forces. There will be wide employment of airborne landings to seize and destroy enemy nuclear means, including those in the immediate battle area and those in the enemy's rear to include nuclear weapons storage areas, control points and reconnaissance means for deploying these weapons.

g. Soviet troops will cross zones of radiation at rapid speeds to prevent contamination of equipment and significant irradiation of troops.

h. Soviet troops will deploy and engage the enemy in such a manner to prevent him from employing his nuclear weapons without destroying his troops.

i. Soviet troops will remain dispersed to reduce the effectiveness of enemy nuclear strikes. Troops will mass quickly and in secret for an advance and attack against the enemy.

---

[129] V. Savkin. *The Basic Principles of Operational Art and Tactics (A Soviet View)*, Moscow, 1972.

Thus, it is clear that Soviet threat forces have not only the means for employing tactical nuclear weapons in a land war in Europe, but also they have established some basic principles for the conduct of this type of warfare. Overall, it may be expected in the initial stages of a confrontation in Europe with Soviet/Warsaw Pact forces that nuclear weapons would be employed against targets away from frontline Soviet positions, i.e., deep NATO targets. In later attacks, these weapons would be employed to achieve conditions for minimum resistance from defending NATO forces. In addition, there appears to be an emphasis on early destruction (in such a conflict) of NATO's capability for launching tactical nuclear attacks. Therefore, it may be expected that initial frontline battles in such a war would be conventional (mid-intensity), but that later frontline battles would be nuclear-supported (high-intensity). However, with the Soviet desire to quickly and effectively destroy NATO's nuclear capability, it may be expected that, during the entire course of such a conflict, nuclear weapons would be employed at varying times to support deep penetration and the destruction of NATO's nuclear capability by destroying delivery systems and storage centers in NATO rear areas.

Conclusion

The purpose of this chapter of the report was to *identify and describe the targets and operational tactics likely to be encountered by US ground forces in a future military conflict.* With respect to this objective, several assumptions were made about (a) where and against whom a future conflict would be fought by US forces, and (b) the level at which such a conflict would be fought. First, it was assumed that Soviet/Warsaw Pact forces or forces equipped and trained by the Soviet Union constitute the primary threat for US ground forces in the near future. Second, it was assumed that a conflict between this identified threat and US ground forces would, for the most part, take place in northern and central Europe. Finally, it was assumed that in a direct confrontation between this threat and US ground forces in Europe, both mid- and high-intensity combat engagements were likely.

Operating under these assumptions, relevant government (including official US Army publications) and non-government documents were reviewed that addressed the problem of Soviet/Warsaw Pact threat in a mid- to high-intensity European environment. In particular, threat forces were discussed with respect to strength, equipment, and operational tactics. Based on this review, several overall observations are noteworthy.

First, as is true with most of the major armies of the world, Soviet/Warsaw Pact forces are basically composed of armored and mechanized units. In addition, much of the air defense artillery and indirect fire (field) artillery systems are mounted on self-propelled and tracked vehicles. Thus, Soviet ground forces are exceedingly mobile and have the capability of rapid movement on the modern battlefield.

Second, from consideration of the nature of current Soviet weapon systems and Soviet tactical doctrine as discussed in this chapter, it is clear that the Soviet military leadership expects future wars to be short and expensive in terms of both personnel and materials. Battles fought in such a conflict are likely to be quite violent due to the lethality and coverage of modern weapons. Obviously, each side in such a war will be fighting to make substantial gains quickly. These gains will be the basis (it is suggested by some) for coming to a political solution of such a conflict. Thus, the successful outcome of any future conflict will depend heavily upon the outcome of these first violent battles.

For example, in an exercise conducted in Europe by the US Army (Hunfeld II),[130] the actions of a covering force composed of two regimental cavalry squadrons, one tank-heavy task force, and one attack helicopter platoon, supported by 14 artillery batteries was investigated as it defended against a Soviet-type reinforced tank division in an assumed first battle of a future European land war. The US forces were deployed across a front 18 kilometers wide with a depth of 18 to 36 kilometers. The aggressor forces commenced their attack at approximately one hour before daylight. The attack began with a 25-minute artillery preparation by more than 300 tubes. As the artillery fire slackened and became more selective, the Soviet-type ground forces attacked. Including the time artillery was firing, the battle lasted for about 90 minutes. US Army maneuver platoons were involved in 33 of the total 50 engagements fought during the battle. Of these, less than half involved more than a platoon sized element of US forces. Thus, the battle was characterized by substantial movement since commanders could often not move quickly enough from one engagement to another to ensure the presence of more than one platoon.

Finally, losses were high. On the US side a total of 83 tanks and armored personnel carriers were lost to aggressor direct and artillery fires. On the aggressor side, a total of 297 tanks, armored personnel carriers, air defense weapons, etc., were lost to US artillery, direct

---

[130] D. Tammien. "How to Defend Outnumbered and Win," *Armor*, November-December 1975, 85(6), 39-45.

fire, and mines. Assuming that this exercise accurately reflected the capabilities of both Soviet and US forces in Europe, the results of this exercise clearly indicate that future wars involving both US and Soviet forces will be exceedingly devastating and quick in execution. In particular, they will involve large numbers of armored vehicles and anti-tank guided missiles, supported by infantry in mechanized combat vehicles. On the Soviet side this will be supplemented by a massive air defense umbrella that could likely preclude significant tactical air support by friendly forces as this was practiced in previous armed conflicts by US forces.[131,132]

Finally, from this discussion of the Soviet/Warsaw Pact forces and equipment and their operational doctrine, it is clear that these forces envision a series of fluid, non-FEBA battles being fought in the next war with massive penetrations aimed at encirclement of opposing forces and the capture of strategic areas in the enemy's rear. Probably, such a war will be fought using conventional weapons in the initial stages until one side or both are compelled to employ tactical nuclear weapons to achieve objectives that cannot be attained with the conventional weapon systems. Thus, a future war in Europe may begin at a mid-intensity level, but it may be expected to escalate to a high-intensity level if either side cannot meet its battlefield objectives.

---

[131] K. Hein. "Old Lessons Learned," *Armor*, September-October 1975, 85(5), 30-36.

[132] S. Canby, *op. cit.*

Implications of the threat literature review for a standard target acquisition methodology. The threat literature review was predicated on the assumption that a future conflict involving US armed forces might be fought against Soviet/Warsaw Pact forces in northern and central Europe. Further, it was assumed that such a conflict would be characterized by conventional and tactical nuclear engagements. Implicit in this analysis of Threat capabilities was the additional assumption that such a conflict would be initiated by the USSR or one of her allies. In particular, this means that the first engagements of a Soviet/Warsaw Pact-US/NATO conflict would be offensive operations launched by Threat forces across the frontiers of NATO nations having common borders with Warsaw Pact nations.

Obviously, after such a conflict has been initiated, it is important to be able to detect advancing Threat forces so that these forces may successfully be engaged and neutralized. Thus, it may be expected that target acquisition systems would be employed in such a conflict to observe likely avenues of approach, selected terrain areas of strategic importance, and important static locations such as crossroads, river crossings, and bridges to detect Threat targets and associated military activity. Further, during a US forces' counteroffensive, it would be important to employ acquisition systems to detect temporary and permanent Threat defensive positions so that these could be effectively engaged and neutralized.

Based on these assumptions, the results of the Threat literature review were studied to identify those characteristics of its tactical operation and composition that have relevance for the methodology of target acquisition system field tests. From this analysis the following characteristics were identified:

a. Threat forces employ a wide variety of armored vehicles to support their combat operations. In frontline areas the armored vehicles most likely to be observed by US field forces are the *T-55* and *T-62* main battle tanks, *PT-76* light amphibious tank, the *BTR-60PB* and *BMP* armored personnel carriers, and *BRDM* reconnaissance vehicles.

b. Threat forces employ a wide variety of mobile and semi-mobile air defense systems to support their combat operations. In particular, the systems most likely to be observed by US field forces in frontline areas are: *ZSU-57-2* and *ZSU-23-4* mobile antiaircraft systems, *SA-4* and *SA-6* surface-to-air missile systems, and the towed *ZPU-4* and *S-60* antiaircraft systems.

c. While Threat forces employ substantial amounts of artillery to support their combat operations, only 120mm mortars and their associated crews are likely to be observed by attacking US units. On occasion, some artillery pieces may be observed in forward areas during a Threat breakthrough assault.

d. Due to the small numbers of helicopters currently known to be in the Threat inventory, it is unlikely that these will be observed with any great frequency on the modern battlefield. However, prior to an attack, it is likely that low-flying high-performance aircraft will be briefly observed above frontline areas.

e. Threat forces employ a variety of antiarmor weapons to form an interlocking defense system effective over ranges from 0 to 3500 meters. These limits basically define the kill zone of the modern battlefield with respect to Threat antitank weapons.

f. Threat forces stress the attack and will resort to the defense only as a temporary expedient.

g. Attacks are generally conducted across narrow fronts (e.g., 1500-2000 meters at the battalion level).

h. Attacks at the regimental level are generally preceded by reconnaissance conducted by elements of the *Reconnaissance Company*. For a front approximately 4500 meters in length, it may be expected that each 1500-meter segment of this front would be scouted by the following combat elements: Two reconnaissance vehicles (*PT-76* or *BRDM*) with a lateral separation of 100 meters supported by a motorized rifle platoon (three *BMPs*) 100 meters to the rear. The *BMPs* would also maintain a lateral separation of 100 meters.

i. A *Probe Attack* may be launched by a Threat regiment if reconnaissance fails to locate unguarded avenues of approach. This type of attack is usually conducted by two motorized rifle platoons and a motorized tank platoon (four tanks). Normally, these forces travel in an echelon formation that approximates a 400 meter (across) by 200 meter (deep) rectangle. Tanks lead this formation followed by *BMPs*.

j. Threat forces train for and plan to operate a 24-hour battle day. During the day *Quick Attacks* may be expected by advancing Threat forces, while at night *Deliberate Attacks* may be expected.

k. A *Quick Attack* at the regimental level may be launched by a reinforced motorized rifle battalion from the line of march upon encountering resistance from opposing forces. In this case, these forces usually deploy from a column formation directly into echelon formation. Depending on the terrain, these forces are likely to spread over an area 1500 meters wide and 1000-2000 meters deep.

l. *Deliberate Attacks* are generally conducted at night. At the regimental level a deliberate attack is usually launched by battalion level forces across a front less than 1500 meters wide. When surprise is essential, no artillery preparation will be employed. At night, these forces will most likely advance in column formation with infantry dismounted and next to their *BMPs*. Tanks will follow and support the infantry.

m. Initially, an advancing US attack force is likely to encounter Threat force *Covering Troops* when moving against a *Deliberate Defense* position. In succession this covering force is likely to consist of (1) reconnaissance elements of the regimental *Reconnaissance Company*, (2) security zone elements consisting of reinforced motorized rifle companies or platoons, and (3) forward or battle outpost elements consisting of reinforced motorized rifle companies or platoons.

n. Initially, US attack forces will encounter first echelon companies when moving against a motorized rifle battalion in a *Hasty Defense* position. Behind these companies will be the bulk of the battalion, including tanks, mortar teams, and mobile air defense weapon systems as well as the remaining motorized rifle companies.

The above characteristics represent the salient factors which describe the current nature of the Threat in terms of the targets and operational conditions likely to be encountered in conflicts in the immediate future with these forces. Thus, during the design and planning phases of a target acquisition test, these characteristics should be considered when developing scenarios which define the targets and operational conditions to be simulated during the conduct of testing. Only in this way will it be assured that these scenarios approximate credible combat conditions and thus provide necessary test situations for measuring the true capabilities of a given acquisition system.

CHAPTER 4

TARGET PRESENTATION METHODOLOGY FOR FIELD TESTING TARGET ACQUISITION EQUIPMENT

Introduction

In the early stages of this effort, Chapter 4 was conceived of as approximating a "How-To-Do-It" manual for test officers. It was hoped that guidance could be provided in the form of scenarios which would essentially standardize target presentation techniques in terms of critical conditions, target types, and tactical configurations. However, the chapter falls shorts of this goal for several reasons.

First of all, the number of conditions or factors shown in the literature to significantly affect target acquisition was larger than anticipated. It had been assumed that perhaps some half-dozen at most would prove to be critical, with the remainder being of minor importance, except, perhaps, under very unusual and circumscribed circumstances. Unfortunately, this assumption, based primarily on a knowledge of results of laboratory studies, proved to be false for studies conducted in a natural environment. The data available indicate a much larger number of factors which simply cannot be ignored.

Secondly, the relationships between a number of factors and observer target acquisition performance are at best imprecisely defined. A factor shown to be all important in one situation may be of no importance in another, and not even measured in a third. This lack of precision makes it virtually impossible to specify particular values or levels of the factors that should be employed in field testing, or even to provide information on how the factors might be employed statistically to predict performance.

As a result of these findings from the literature, it became apparent that complete control of the factors that might be critical in any particular situation would be impossible in field studies. Even if each factor could be divided logically into only "high," "medium," and "low" levels, the number of possible combinations of all factors would number well into the millions. The duplication of conditions from one test to the next, or even from one day's trials to the next in the same test, would be rare.

Because the original conception proved unrealistic, a less ambitious approach has been taken in this chapter. Rather than the precise specification of conditions, target types and tactical configurations, the guidance provided is much more general in nature. However, a number of specific "dos" and "don'ts" are listed. These are based on shortcomings, problems encountered, and errors committed as reported or observed in past field studies. Therefore, while the chapter does not provide complete step-by-step guidance to the test officer, awareness of the information presented and adherence to the principles listed should both help standardize target presentation methodology, and ensure the presentation of tactically valid target situations.

An Approach

Earlier in this report it was pointed out that investigations of the acquisition process (detection, recognition, and identification) involve at least four basic components: a target, a background, a task, and an observer. Further, it was shown that systematic variations in the defining attributes of these components are often associated with systematic variations in measures of acquisition performance. Therefore, in planning, designing, and conducting tests developed to evaluate a given target acquisition system, it is important that the delineation and interaction of these components be given careful consideration. In particular, this means that the principles of systematic variation and experimental control must be applied when developing appropriate test situations for answering specific test questions.

In military testing this problem is particularly acute when it is desired to determine the suitability of a given target acquisition system for use in combat. Only if the test situation is credible (i.e., the test targets and test conditions faithfully simulate the characteristics of the anticipated combat targets and operational conditions) and free from extraneous sources of bias can it be expected that the test results will be valid and reliable and thus represent the "true" operational capabilities of the tested system. Further, it is only from such valid test results that military planners can make intelligent decisions concerning procurement questions and the appropriate use and deployment of the tested system.

More often than not, the problem of developing credible and bias-free test situations for evaluating the combat capabilities of target acquisition systems centers around the interrelated problems of (a) how to control variations in both target and non-target factors so that extraneous bias is minimized or eliminated; (b) what types of targets and operational conditions to employ during testing; and (c) how these targets should be presented to observers. Collectively, these problems may be referred to as the *target presentation problem*. It is the purpose of this chapter to suggest and discuss solutions to the various aspects of this problem for field tests of ground-to-ground acquisition systems.

The Control of Target and Non-target Factors to Eliminate or Reduce Test Bias

During the planning and design phases of a target acquisition field test, it is necessary that test personnel consider and take into account in some manner the potential impact of both target and non-target variables on the test results. In this way, the potential biasing of the test data can either be minimized or eliminated. It is the purpose of this section of the report to suggest some specific guidelines that may be followed by test personnel to help avoid or minimize errors that may invalidate test data and, ultimately, test conclusions. In general, these guidelines are based on the results of the literature review presented in Chapter 2, which was conducted to identify those factors that are important in the target acquisition process. However, some of these guidelines are not specifically associated with any particular acquisition factor, but are mentioned since they are in keeping with good experimental procedure.

Target factor guidelines. Table 5 lists target factors (and their expected effects) which were found or are likely to influence the acquisition process in a field situation. During the conduct of an acquisition field test, it is extremely important that test targets realistically simulate or conform to actual combat targets. Otherwise, test data are likely to either over- or underestimate system operational capabilities. In order to minimize the likelihood of this happening, the following guidelines are suggested with respect to the target factors listed in Table 5.

a. The area (size) of the test target presented to observers during testing should correspond as closely as possible to the area (size) that would be presented by a comparable target in a combat situation. If targets of the same size are not available, remember, larger targets are likely to be acquired at greater ranges, while smaller targets are likely to be acquired at shorter ranges. Thus, in these circumstances, test results must be adjusted, if it is desired to generalize them to actual combat targets.

Table 5. Target Factors That May Affect the Acquisition Process and Their Expected Effects

1. *Target Size*. Under photopic and scotopic illumination conditions, as target size is increased, the probability of target acquisition increases.

2. *Target Shape*. Target shape may be a factor in target acquisition. It has not been established what target shapes are more or less likely to differentially affect the probability of target acquisition in a field situation. It may be hypothesized that as target shape deviates from those shapes normally encountered in a natural field setting, the probability of target acquisition will increase.

3. *Target/Background Color Contrast*. Under illumination conditions for which target and background color can be discriminated, as target/background color contrast is increased, the probability of target acquisition increases.

4. *Target/Background Brightness Contrast*. Under photopic and scotopic illumination conditions, as target/background brightness contrast is increased, the probability of target acquisition increases.

5. *Target-to-Observer Range*. Under photopic and scotopic illumination conditions, as target-to-observer range is increased, the probability of target acquisition decreases. However, this relationship may be differentially influenced by other factors important in the target acquisition process, e.g., use of visual aids, presence of vegetation.

6. *Target Duration*. For suprathreshold targets exposed for longer than one second, as target exposure is increased, the probability of target acquisition increases. For targets exposed for less than one second, the probability of target acquisition is a function of both exposure time and target brightness.

7. *Target Movement*. Under photopic and scotopic illumination conditions, the probability of target acquisition is lower for stationary targets than for moving targets.

8. *Target Speed*. Under photopic and scotopic illumination conditions, as target speed is increased, the probability of target acquisition increases. However, this relationship may be differentially influenced by other factors in the target acquisition process, e.g., the complexity (in terms of amount and distribution of vegetation as well as variations in terrain relief) of the terrain in which targets appear.

b. Test targets should be of the same shape as the combat target they are simulating. Use tanks to simulate tank targets, trucks to simulate truck targets, armored personnel carriers to simulate armored personnel targets, etc.

c. Require that the angle at which the test targets is viewed be the same as would occur in combat. Do not present views of test targets that are unlikely to be seen. For example, in attack situations, it would be appropriate to have observers view the fronts of a target. In this case, side views would generally be inappropriate.

d. Allow target shape to vary as it would tactically, i.e., during testing allow targets to maneuver as they would in combat within the constraints of the tactical situation being modeled.

e. Targets should be colored as they would be in combat. This includes having the targets painted in camouflage patterns. Do not use brightly colored targets as test targets, since such targets are unlikely in combat.

f. Document the physical appearance of targets as they appear during testing with high quality photographs. Color photographs are generally to be preferred to black and white photographs.

g. Unless called for by the purpose of the testing, do not have dark colored test targets passing in front of light colored backgrounds and vice versa.

h. Unless called for by the purpose of the testing, do not required targets to appear against a sky background or against other backgrounds which would result in a high target/background contrast ratio (either color or brightness contrast ratio).

i. Require that moving targets (e.g., targets advancing toward an observer employing an acquisition system) begin at target-to-observer ranges which are greater than the expected range of the system. In this way, the likelihood of acquisition as a function of range can be determined for the system for the specific targets and target conditions being studied.

j. Unless required by the purposes of the test, permit targets to mask themselves as they would be likely to do in a combat situation.

k. Do not select target approaches that provide for maximum observer viewing time. Instead, choose target approaches which tend to minimize or provide viewing times characteristic of a combat environment, e.g., a few seconds.

l. Require that test targets move with respect to the observer only in the same directions they would be likely to move in a combat situation. For example, in an attack situation, it is appropriate for targets to move towards the observer, not laterally.

m. Do not use stationary targets when it is more appropriate to study moving targets. Do not try to generalize from stationary target to moving target situations, since the acquisition probabilities are different.

n. Have targets move at the speeds appropriate for the terrain conditions of the test site and the particular tactical situation being portrayed.

o. Do not deliberately limit target speed (either fast or slow) for any other purpose than realism. For example, if a Threat vehicle has an operating speed of 10 to 15 kilometers per hour on the road, then the speed of the test target simulating the Threat vehicle should be limited to 10 to 15 kilometers per hour. Otherwise, the particular speed that the test target should travel should be determined by what is tactically valid.

Environmental factor guidelines. Table 6 lists the environmental factors (and their expected effects) which were found to influence the target acquisition process in the field. Generally, it may be expected that these factors will be under only the most limited control of test personnel. Therefore, it may be expected that variations in these factors will likely contribute most heavily to the imprecision of the data collected during a field test evaluation. In order to minimize and/or account for the bias in test data that may be the result of the operation of environmental factors, the following guidelines are suggested:

a. For each data collection trial, determine the meteorological visibility at the test site. Later, and assuming a sufficient amount of variability in measures of meteorological visibility, any differences in the test data due to variations in meteorological visibility may be determined (and extracted if this is required) by appropriate statistical techniques.

b. For each data collection trial, indicate whether or not dust, smoke, rain, fog, etc., are present. Such information may be reported by both test monitors and observers. Then, as was true for meteorological visibility, any performance differences due to the presence of dust, smoke, rain, fog, etc., may be determined (and extracted if this is required) during analysis of the test data.

Table 6. Environmental Factors That May Affect the Acquisition Process and Their Expected Effects

1. *Condition of the Atmosphere.* The condition of the atmosphere (presence versus absence of dust, fog, haze, rain, smoke, or snow) may be a factor in target acquisition. In particular, as the clarity of the atmosphere (as measured by meteorological visibility) is increased, the probability of target acquisition increases.

2. *Level of Ambient Illumination.* The probability of target acquisition is lower under scotopic conditions of illumination than under photopic conditions of illumination. Further, as the level of ambient illumination is increased, the probability of target acquisition increases. However, increments in the probability of target acquisition are larger for increasing levels of scotopic illumination than for increasing levels of photopic illumination.

3. *Terrain and Vegetation.* (a) As both terrain relief and the amount of vegetation are increased, the probability of target acquisition decreases. (b) As seasonal changes occur which reduce the amount of extent of vegetation which interferes with the establishment of lines-of-sight between the target and the observer, the probability of target acquisition increases. (c) As the height, density, and type of vegetation changes in such a way to interfere with the establishment of lines-of-sight between the target and the observer, the probability of target acquisition decreases.

4. *Location of the Target in the Terrain.* Target location may be a factor in target acquisition. This will be true to the extent that variations in target location are differentially associated with variations in vegetation or terrain relief which mask lines-of-sight between the target and the observer. Also, this will be true when targets are located in areas searched infrequently or when target location and observer expectations about target location are disparate.

5. *Illuminant Position.* As the position of the light source illuminating a target changes such that target/background brightness contrast is increased, the probability of target acquisition increases. This is particularly true for targets which initially have a low target/background brightness contrast. In particular, as the illuminant position is changed to either frontlight or backlight target, the probability of target acquisition increases.

6. *Ambient Temperature.* Temperature (either heat or cold) extremes may affect target acquisition. While no empirical field data for a target acquisition situation are available, data from field research involving related visual tasks suggest that under conditions of extreme heat or cold, the probability of target acquisition is likely to decrease.

c. During the planning and design phases of a field test, determine the likely climatic conditions under which the acquisition system to be tested will be operated in combat. Then, plan to conduct the testing under these conditions of climate. In this way, the validity of the test data will likely be enhanced, since the similarity between test conditions and actual combat conditions will have been maximized.

d. Unless required by the purposes of the testing, do not wait for "ideal" days to collect test data in order to maximize system acquisition probabilities. During combat, it cannot be assumed that ideal conditions will prevail. As such, it is appropriate to determine the acquisition capabilities of a tested system under less than ideal conditions. In this way, the full range of acquisition capabilities as a function of variations in atmospheric conditions may be determined and accounted for. Therefore, it is necessary for each day of the testing to record information which describes the atmospheric and climatic conditions for that day.

e. During the course of an acquisition test, do not simply report data concerning light levels in terms of such descriptors as starlight, moonlight, nighttime, daytime, morning illumination or afternoon illumination. Such terms are imprecise and as such do not reflect the actual level of illumination at any given time. Further, because such terms are imprecise, the actual light levels to which they refer may not be the same for one study as for another. Therefore, it is appropriate during the conduct of a given acquisition study to measure on each data collection trial the level of ambient illumination at the test site (preferably at the level of the observer's eye) in foot-candles or other suitable physical measurement units.

f. Document the terrain of the test site by adequately sampling and photographing it. Color photographs are preferable to black and white photographs. Pay particular attention to the sampling process so that significant terrain and/or vegetation variations are captured and documented photographically. Such information may be useful during the data analysis phase of the test in accounting for or explaining variations in the test results.

g. During the planning phase of the field test, identify geographic areas for the conduct of testing that are as similar as possible to the geographic areas in which the tested system will probably be operated. In this way, the results of testing will have maximum validity for actual combat situations. Such factors as the amount of vegetation (both undergrowth and primary growth), average height of the ground cover, shape of the terrain, and the number and density of obscuring terrain features should be taken into account in choosing the terrain appropriate for the conduct of testing.

h. When situating targets in the terrain selected for the testing, ensure that targets are not located in unvegetated areas, unless such areas are characteristic of the terrain in which the system is likely to be employed.

i. In identifying routes along which targets may advance during testing, do not choose routes through the easiest terrain so that target acquisition is ensured or for the purpose of aiding the observers in any way.

j. Record the ambient temperature on each data collection trial. If possible, record both the Dry Bulb Temperature (DBT) and the Wet Bulb Temperature (WBT). Such information may be useful during the data analysis phase of the test in accounting for or explaining variations in the test results.

k. During the planning and design phases of a test, plan data collection trials so that targets are illuminated from the front, rear, and sides. In this way, variations due to illuminant position may be accounted for or extracted from the test data.

l. During each observation trial, record the date, time of day, and geographic location. From this information, the sun angle associated with each measure of performance may be computed. In this way, variation in the test results due to varation in sun angle may be accounted for or extracted from the test results.

m. Do not plar to collect all test data at a particular time of the day just because this is easier. It is not realistic to expect actual battlefield targets to only appear at one particular time of the day. In fact, it is likely that targets on the modern battlefield will be present at all times of the day.

Task factor guidelines. Table 7 presents the task factors (and their expected effects) that were found in Chapter 2 of this report to significantly influence the acquisition process. During the conduct of an acquisition field test, it is extremely important that these factors be controlled in some manner so that they do not differentially affect observer performance. Otherwise, it may happen that the test data collected from these observers will not clearly reflect the capabilities of the system being tested, but will be contaminated by the uncontrolled variations of task factors. The following guidelines represent some basic suggestions as to how these factors may be controlled in a given acquisition situation:

Table 7. Task Factors That May Affect the Acquisition Process and Their Expected Effects

1. *Movement of the Observer.* The probability of target acquisition is lower for stationary observers than for moving observers, but only when the target is moving.

2. *Size of the Search Area.* As the size of the area searched for targets is increased, the probability of target acquisition decreases. However, this relationship may be differentially influenced by other factors involved in the target acquisition process, e.g., target/background brightness contrast, target exposure time, and level of ambient illumination.

3. *Amount of Observer Practice.* The amount of practice an observer has completed on a target acquisition task may affect the probability of target acquisition. In particular, it may be expected that with increasing amounts of practice, the probability of target acquisition will increase.

4. *Search Strategy.* The method of search employed by the observer during target acquisition (either free or structured search) may affect the probability of target acquisition. It is currently not known what parameters define the conditions under which a given type of search will increase the probability of target acquisition. As a result, unless dictated otherwise, the search strategy employed during acquisition should correspond to the strategy typically employed in a given situation or to that required by any equipment constraints.

5. *Duration of Observation.* To the extent a target acquisition situation approximates a vigilance situation, it may be expected that as the duration of observation increases, the probability of target acquisition will decrease. However, to the extent that a target acquisition situation approximates an active visual performance situation, it may be expected that as the duration of observation increases, the probability of target acquisition will remain unchanged insofar as the situation is not complicated by debilitating physiological events, e.g., loss of sleep, drugs, anoxemia.

a. During the planning phase of an acquisition field test, determine whether the observer will be allowed to move or will be required to remain stationary during each data collection trial. In general, this decision should be based on the specified (or anticipated) doctrine for the use of the target acquisition system being tested. Remember, since the probability of acquisition is lower for stationary observers looking for moving targets than for moving observers looking for moving targets, the results obtained for one of these situations will not be representative for the other situation. Therefore, if information is required for both of these observer-target situations, it will be necessary to design the test so that both situations are modeled. On the other hand, for situations involving moving and stationary observers scouting for stationary targets, the results for these situations are generally comparable and thus the results from one situation may be generalized to another (given that all other factors are equal).

b. The size of the search area is likely to vary with the tactical situation, the number of acquisition systems available, the weather, and the size of the area through which Threat forces are most likely to approach. Generally, it is appropriate to define the search area in keeping with the planned (or expected) deployment doctrine defining the use of the system being tested. However, in some instances, it may be necessary to employ smaller search areas in order to accommodate target situations in which smaller numbers of targets are fielded over a given terrain area (so that target density is kept constant). In general, it is probably better to limit search sector size and maintain a realistic target density than to study a large, programmed search area with targets spaced to create unrealistic target densities.

c. Within a given search area, vary the location from which moving targets can approach an observer. Similarly, for situations involving stationary targets, vary the position of the targets in a given search area. In this way, observers will be prevented from learning the exact location of targets or their routes of advance. In turn, this will likely preclude observers from artificially limiting the area that they actually search.

d. Remember, during testing the observers will become practiced. Therefore, at the end of testing their performance will probably be superior to their performance at the beginning of testing. This possibility should be investigated during the analysis of the test results.

e. Prior to actual data collection trials, train observers in exactly the same way that personnel would be trained to operate the system in combat. Do not provide observers more training than it can be expected that the "typical" observer in the field would receive.

f. During data collection, watch observers and determine what they are doing when they search for targets. After all observation trials have been completed by a given observer, debrief the observer on the search method he employed during acquisition. During the data collection phase of the test, attempt to determine if more successful observers employ search strategies that differ from those employed by less successful observers.

g. Do not force a particular search strategy on test observers, unless the employment doctrine for the system being tested calls for a particular strategy.

h. During testing, have observers employ the system being tested for lengths of time (shifts) that are characteristic of the combat deployment of the system. Watch for performance differences as a function of time on shift. Any such differences may suggest changes in the doctrine for system deployment and manning.

i. During long periods of observation, do not present targets at such regular or frequent intervals that observers can learn to anticipate the targets.

j. During observation periods of long duration, do not employ rates of target presentation that are unrealistic. In some cases, it may be appropriate for observers to go whole shifts without any targets being presented. Targets in a combat situation will not necessarily appear at regular intervals. In fact, it may be expected that there will be long periods between the observation of targets which correspond to lulls in combat operations of both friendly and Threat forces.

k. Remember, as the acquisition situation becomes more and more similar to a vigilance situation, performance decrements as a function of time on the job will be more likely. On the other hand, if the acquisition situation requires the observer to be visually and cognitively active, performance decrements as a function of time are less likely.

Observer factor guidelines. Table 8 presents the observer factors (and their expected effects) that may influence the acquisition process in a field situation. In general, the control of these factors will be accomplished by (a) the selection procedures employed for obtaining observers to participate in the test, or (b) the test procedures including instruction designed to limit observer behavior. The following are suggested guidelines for procedures that will generally ensure the control of these factors:

a. Observer visual acuity is a significant factor in the acquisition process. This factor should be controlled during all acquisition trials. Observer visual acuity should be measured for each observer participating in the test. Also, it may be appropriate to minimize the effect of this factor by setting minimum acuity requirements for observers.

Table 8. Observer Factors That May Affect the Acquisition Process and Their Expected Effects

1. *Visual Acuity.* As the level of observer visual acuity is increased, the probability of target acquisition increases.

2. *Observer Height (Eye Level Above the Ground).* As the above-ground level of the observer's eyes is increased, the probability of target acquisition increases. For this relationship to occur, the level of ambient illumination must exceed starlight. Further, the magnitude of this relationship will increase as the terrain in which target acquisition is conducted presents fewer obstructions to vision.

3. *Past Experience and Training.* With increases in the amount of relevant experience or training in the area of target acquisition, it may be expected that the probability of target acquisition will increase.

4. *Motivation.* Motivational factors may affect target acquisition. However, it is currently not clear exactly what factors affect this process in a field situation, or what form the relationship between motivational factors and the probability of target acquisition takes.

b. In deploying an acquisition system during testing, the position of the device and observer above ground level should be the same as that expected for combat situations. If it can be anticipated that the system will be deployed at a variety of above-ground heights, these should be evaluated during testing, since differences in above-ground eye level are associated with differences in the probability of acquisition.

c. Observers chosen for the testing should have the same kinds of background and experience that can be expected of "typical" combat personnel who would operate the system on the battlefield.

d. Military personnel on a test will not be as motivated as combat troops, whose lives will depend on their performance. Therefore, for this reason alone, test results will probably underestimate the capability of the system being tested. However, the motivation of these personnel can be enhanced to some degree with little effort. Generally, if test observers feel that everything reasonably possible is being done for them, they will approach the test situation with a positive attitude and do the best job they are capable of doing.

e. During testing, listen to the test observers. They may make comments about the test that never occurred to test planners. Further, if it is explained why something is being done or not being done, the observers are less likely to complain and lose motivation. Finally, if something can be done about any complaints that arise during testing, motivation will usually rise. If nothing can be done about such complaints, an explanation of "why" will frequently help maintain motivation.

f. Do not make test observers engage in "busy work." Their duties during the test should be as similar to combat as is possible. Further, they should know this. In this way, the observers are likely to feel that what they are doing is worthwhile and, thus, have a high level of motivation.

<u>A final note</u>. From the results of Chapter 2, it can be seen that a wide variety of factors may conceivably influence the results of a target acquisition field study. However, in planning for such a study, the basic requirements and objectives of the study will, in general, determine the particular factors that will be important during the conduct of the research. In particular, some of the factors listed in Tables 5, 6, 7, and 8 will be more important (have greater relevance) than other factors. In the final analysis, though, all of these factors must be accounted for in some manner during the conduct of the research. This means that during the

conduct of a given acquisition study the factors discussed in Chapter 2 must either be evaluated in some way or they must be controlled. By applying the guidelines suggested in the previous section of this chapter and as well by being familiar with the results and implications of the review of these factors (as discussed in Chapter 2), it should be possible to ensure that future acquisition studies will be more valid and comparable. Further, through the use of appropriate experimental design techniques (randomization, counterbalancing, statistical control strategies) in conjunction with this information, validity will be further enhanced. That is, by applying the results of the acquisition literature review, the control guidelines discussed above, and the principle of good experimental design, it is highly likely that test personnel should be able to provide valid data concerning the capabilities of target acquisition systems.

Identification of Targets and Operational Conditions

Target acquisition systems are primarily designed to improve the human observer's ability to sense targets, i.e., objects that the observer is interested in locating and doing something about. Most acquisition systems are designed with some idea about the targets against which they will be deployed and the specific operational conditions under which they will function. Once the major objectives of a field test of a system have been determined, the targets and the operational environment are implied to some extent. For example, once it is clear that an acquisition system is to be tested to determine its combat effectiveness in a northern or central European terrain against attacking Warsaw Pact armored vehicles, it is conceptually evident what types of targets should be employed or simulated during testing. Further, it is clear what type of combat situation the testing should model.

Thus, by the time a given acquisition system is ready for field testing in a credible environment, it is usually clear at a general level what characteristics define this environment. Similarly, it is usually clear what kinds of specific targets should be fielded against the acquisition system.

However, the actual translation of this information from the conceptual to the physical level usually presents considerable difficulties for personnel planning and conducting a test. This is because frequently the necessary resources (actual or simulated Threat targets and knowledge of the most recent Threat forces doctrine and techniques) are often unavailable or inaccessible to test personnel. This incomplete knowledge can lead to the employment of targets and to tests conducted in operational environments which resemble only in the most general ways the targets and conditions likely to be found on the battlefield. As indicated above, data collected under such conditions may not reflect the "true" capabilities of the tested systems and, thus, may lead military planners to invalid decisions for the use of the system. Therefore, it is important that test personnel choose and employ targets and operational conditions that closely simulate the characteristics of actual combat targets and likely battlefield circumstances. The remainder of this section will address this aspect of the target presentation problem, i.e., what types of targets and operational conditions to employ during testing.

The Threat literature review suggested that targets most likely to be encountered on the modern battlefield will be organized groups of armored combat vehicles and self-propelled and semi-mobile (towed) air defense systems. Tables 9 and 10 list the armored vehicles and air defense systems most like to be encountered and/or observed by US forces in front-

Table 9. Threat Armored Fighting Vehicles Most Likely to be Observed by US Forces on the Modern Battlefield

Vehicle	Main Armament	Crew Size
T-55 Tank	100mm Rifled Bore Gun	4
T-62 Tank	115mm Smoothbore Gun	4
PT-76 Recon Vehicle	76mm Low Velocity Gun	3
BRDM Recon Vehicle	7.62mm (or 12.7mm) Machinegun	5
BTR-60PB	7.62mm Machinegun	10
BMP	73mm Low Pressure Gun Sagger Antitank Guided Missile 7.62mm Coaxial Machinegun	11

Table 10. Threat Self-Propelled and Towed Air Defense Systems Most Likely to be Observed by US Forces on the Modern Battlefield

Air Defense System	Characteristics
ZSU-57-2 Self-Propelled AA Gun	Twin 57mm guns mounted on medium tank chassis
ZSU-23-4 Self-Propelled AA Vehicle	Four 23mm guns mounted on light tank chassis
SA-4 (Ganef) Surface-to-Air Missile System	Twin missiles mounted on mobile, tracked launcher
SA-6 (Gainful) Surface-to-Air Missile System	Three missiles mounted on mobile tracked launcher
ZPU-4 Towed AA Machinegun	Quadruple mounted 14.5mm machineguns
S-60 Towed AA Artillery	Single 57mm gun

line combat situations. Thus, in future target acquisition studies and tests, targets which are similar to these, in terms of such factors as size, shape, color, etc., should be employed.

Further, the Threat literature review suggests that the most common type of field situation which will be encountered on the modern battlefield (at least in the initial stages of such a conflict) will be US forces in a defensive position. Thus, the most appropriate scenarios for studying target acquisition system capabilities should be those which involve the acquisition of advancing armored combat vehicles. In these scenarios, Threat forces would advance on defensive positions equipped with target acquisition systems.

Under conditions of low illumination (e.g., twilight and less than twilight illumination levels), the advancing Threat forces would be the leading elements of a Threat force conducting a deliberate attack. Under daylight illumination, Threat forces would be conducting a probing attack or a quick attack from a march column formation. Due to the fact that the intent of field testing is to assess the capabilities of a system under credible combat conditions, it would be appropriate to employ test conditions in which artillery fire and its effects (smoke, dust, etc.) were simulated in order to determine how the system would be affected.

Finally, it would also be appropriate to study scenarios in which US forces would perform reconnaissance against a Threat deliberate defense position. In this case, personnel would deploy the target acquisition system and observe stationary and/or in place Threat targets deployed either in a deliberate or hasty defense situation. Alternatively, assuming a mobile acquisition system, scenarios should feature advancing

US forces equipped with the system and who would perform reconnaissance of the elements of a Threat covering force deployed forward of a deliberate defense position.

Methods of Target Presentation

The manner in which targets should be presented during a field test concerns the problem of how targets should be made available for observation. This will depend on several factors: (a) the operational situation, (b) the numbers and kinds of targets to be presented, and (c) the expected behavior of the targets.

In the previous section of this chapter it was determined that three operational situations would be most likely:

a. an attack situation in which concealed acquisition systems observe leading elements of a Threat deliberate attack under low illumination conditions, or an attack situation in which concealed acquisition systems would be employed to observe either a reconnaissance force, a force conducting a probing attack, or a force conducting a quick attack from a march column formation under daylight conditions.

b. a stationary reconnaissance situation in which US forces would deploy an acquisition system to observe stationary Threat forces in either a deliberate or hasty defense position.

c. a mobile reconnaissance situation in which US forces would employ an acquisition system to acquire and study Threat covering forces located forward of a deliberate defense position.

Based on the results of the Threat literature review, the appropriate numbers and the tactical disposition of the targets for each of the above operational situations is as follows:

a. RECONNAISSANCE BY THREAT RECONNAISSANCE COMPANY PRIOR TO ATTACK (DAY OR NIGHT)

Width of Front: 4500 meters.

Disposition of Company Elements: Each 1500 meter section of the front is likely to be scouted by two reconnaissance vehicles (*PT-76* or *BRDM*) with a lateral separation of 100 meters supported by motorized rifle platoon (three *BMPs)*

100 meters to the rear. The *BMPs* would also maintain a lateral separation of 100 meters.

b. ATTACK BY THREAT BATTALION AT NIGHT

Width of Front: 1500 meters or less.

Advance to Attack: Advance in company column formation with *BMPs* and dismounted infantry leading or next to tanks. *BMPs* following tanks and infantry. At 100 meters or less, forces will deploy into echelon formation. Between-column and vehicle distances of about 25 meters are maintained.

First Echelon: Twelve medium tanks (*T-55* or *T-62*) deployed in three groups of four tanks. Lateral between-group distances of 500 meters and lateral within-group tank distances of 25-30 meters are maintained. Dismounted infantry, in 30 eight-man groups on line, will advance with tanks.

Second Echelon: Twenty-seven *BMPs* in three groups of nine *BMPs*. Lateral between-group distances of 500 meters and lateral within-group *BMP* distances of about eight meters are maintained. Immediately following each *BMP* group a single *BMP* is situated about eight meters behind the middle *BMP* of each group.

Between-Echelon Distance: Up to about 300 meters.

c. ATTACK BY THREAT BATTALION DURING DAY

Width of Front: 1500 meters.

Advance to Attack: At 4000-6000 meters from FEBA, Threat forces will advance in company column formation with tanks leading, e.g., four tanks followed by ten *BMPs* per company with between-vehicle distances of 50 meters. Between-column distances are 50 meters. A total of three company columns advance.

At 1000-3000 meters from FEBA, Threat forces will deploy into nine platoon columns, e.g., one tank followed by three *BMPs* per platoon, except for second, fifth, and eighth platoons. For these platoons, one tank is followed by four *BMPs*. For each column a tank-to-*BMP* distance of about 100 meters is assumed, while *BMP*-to-*BMP* distances will be about 50 meters. Between-column distances of about 50 meters for the first three, second three, and last three platoons are appropriate. Between-column distances of about 100 meters between the third and fourth, and the sixth and seventh platoon columns should be maintained.

At 1000 meters or less from FEBA, Threat forces deploy in echelon formation with three companies across or in echelon formation with two companies across with a third company

1000-2000 meters to the rear in platoon column formation. See Figures 16 and 17 for detailed layout of these formations.

d. PROBING ATTACK BY REINFORCED MOTORIZED RIFLE PLATOONS DURING DAY

Width of Front: 1500 meters.

Disposition of Forces: Two motorized rifle platoons (six *BMPs*) and a motorized tank platoon (four tanks, either *T-55* or *T-62*) in an echelon formation that approximates a 400 meter (across) by 200 meter (deep) rectangle. The tanks will lead the formation with a lateral separation of 100 meters.

The *BMPs* (in pairs) will follow the tanks with a lateral separation of about 150 meters. A between-echelon distance of about 100 meters is maintained.

e. RECONNAISSANCE OF DELIBERATE THREAT DEFENSE SITUATION FOR THREAT BATTALION

Width and Depth of Forces: 5000 meters (width) by 4000 meters (depth).

First Echelon Forces: Two reinforced motorized rifle companies, i.e., eight tanks (*T-55* or *T-62*) and 20 *BMPs* plus a battalion antitank platoon (two *Suitcase Saggers*).

Second-Echelon Forces: One reinforced motorized rifle company, i.e., four tanks (*T-55* or *T-62*) and 10 *BMPs*, plus three *Sagger-BRDM* from regiment, six mortar (120mm) teams, and three mobile air defense systems (*ZSU-23-4* or *ZSU-57-2*).

Deployment of Forces: A typical example of these forces' deployment is presented in Chapter 3, Figure 14.

f. RECONNAISSANCE OF HASTY DEFENSE SITUATION FOR THREAT BATTALION

Width of Front: 3000 meters (width) by 4000 meters (depth).

First Echelon Forces: Two motorized rifle companies (20 *BMPs*) plus a battalion antitank platoon (two *Suitcase Saggers*).

Second Echelon Forces: Tank company (12 tanks), motorized rifle company (10 *BMPs*), three *Sagger-BRDMs*, six mortar (120mm) teams, and three mobile air defense systems (*ZSU-23-4* or *ZSU-57-2*).

Deployment of Forces: A typical example of these forces' deployment is presented in Chapter 3, Figure 15.

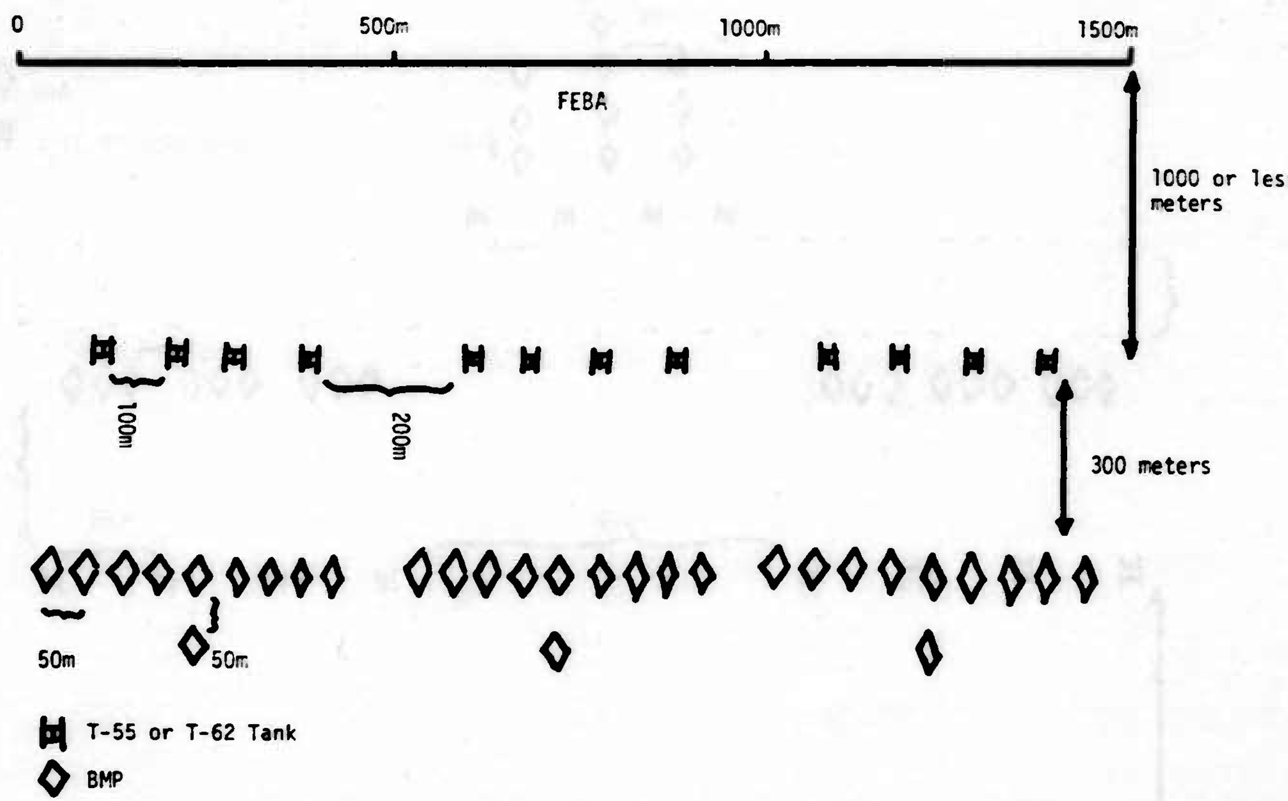


Figure 16. Deployment of attacking threat battalions in three companies across echelon formation.

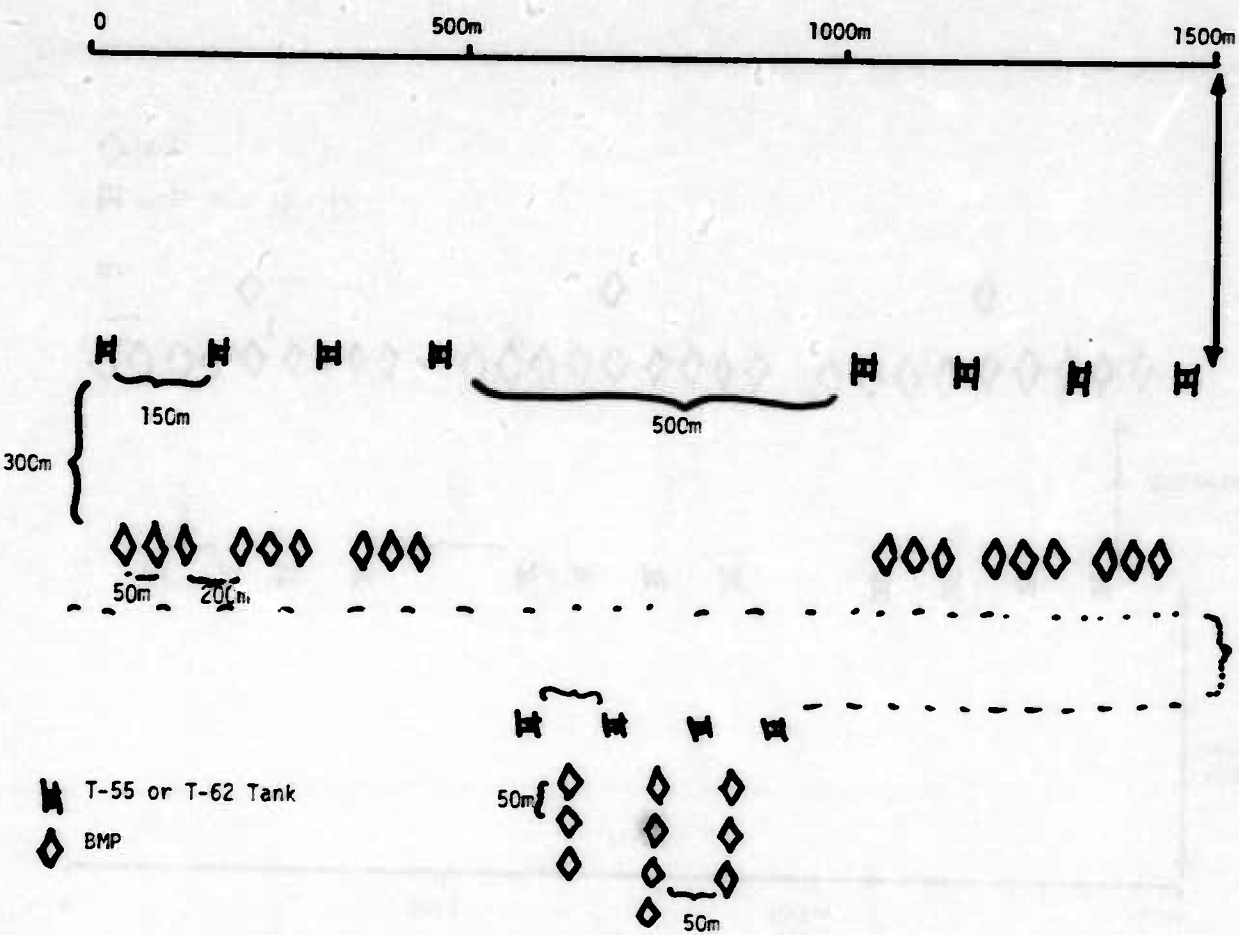


Figure 17. Deployment of attacking threat battalions in two companies across echelon formation with third company 1000-2000 meters to the rear.

g. MOBILE RECONNAISSANCE THROUGH THREAT COVERING FORCE FOR A BATTALION LEVEL THREAT DELIBERATE DEFENSE

Width and Depth of Forces: 5000 meters (width) by 16 kilometers (depth).

Forces Likely to be Encountered First: Security forces will be located on the most likely routes of advance. Either reinforced motorized rifle platoon (one tank and three *BMPs)* or reinforced motorized rifle company (four tanks and 10 *BMPs).*

Disposition of Forces: Figure 18 presents a typical example of the disposition of a reinforced platoon, while Figure 19 presents the typical disposition of a reinforced company.

Forces Likely to be Encountered Second: Forward positions are located about 10 kilometers behind security forces manned by reinforced motorized rifle platoons or companies. Also, battle outposts will be located about 15 kilometers behind security forces if forward positions are not established. These are manned by motorized rifle platoons and usually do not have tank support.

Relative Dispositions of Covering Forces: In Chapter 3, Figure 13 presents the typical dispositions of Threat covering forces for a Threat motorized rifle battalion.

It is evident from the above descriptions that substantial numbers of vehicles and personnel will be required to simulate the operational situations likely to be encountered on the modern battlefield. However, the information obtained during the review of the Threat literature indicates it highly likely in a future conflict with these forces that large aggregations of equipment and personnel will be encountered on a regular basis during combat operations. Thus, as described, the above situations represent credible (i.e., valid) target arrays for testing target acquisition systems deployed for combat, surveillance and observation.

On the other hand, from a practical viewpoint, it may prove to be exceedingly difficult or impossible to model the situations described above in terms of the personnel and equipment requirements. This is because large groups of combat personnel and equipment are frequently

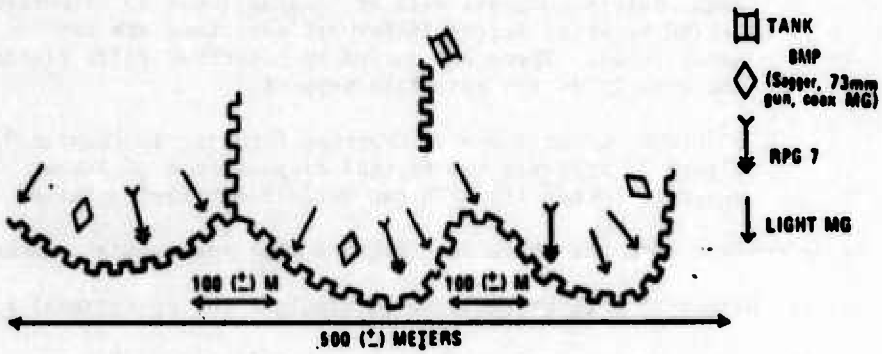


Figure 18. Typical deployment of a reinforced threat motorized rifle platoon.[2]

---

[2]**Reproduced from TC 7-24, *Antiarmor Tactics and Techniques*, Department of the Army, US Army Infantry School, Fort Benning, Georgia, 30 September 1975.**

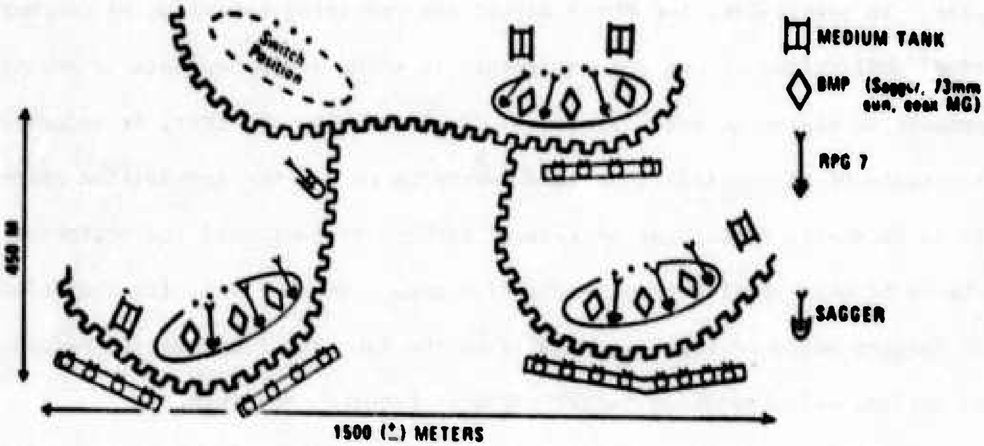


Figure 19. Typical deployment of a reinforced threat motorized rifle company.[3]

---

[3]Reproduced from TC 7-24, *Antiarmor Tactics and Techniques*, Department of the Army, US Army Infantry School, Fort Benning Georgia, 30 September 1975.

unavailable for field testing (unless such tests are of significant interest or importance to high-level military authorities or planning agencies) due to costs, prior training and/or operational commitments. As a result, it is necessary to consider how the above situations might be reduced in scope so as not to exceed the resource capabilities of test organizations.

Perhaps the most practical solution to this potential problem is to employ target situations which have been substantially scaled down in size. In particular, for those situations requiring battalion or company sized collections of men and equipment, it might be appropriate to employ company or platoon sized collections, respectively. Further, in reducing the scale of these situations (and depending on how the acquisition system is to be used), deployment of reduced numbers of personnel and equipment should be over smaller frontages and/or area. In this way, the densities of targets would be kept essentially at the same level as the full-scale situation, while reducing target resource requirements sharply.

Further, in implementing a scale reduction strategy, it is imperative that the personnel and equipment targets actually fielded behave in the manner required by the full-scale operational situation. For example, in an attack by a reinforced motorized rifle company employed in the place of a reinforced motorized rifle battalion, the company level force should maintain the same relative positions and advance at the same rates as the battalion. Similarly, in a situation in which a battalion minus or a company plus force was employed to simulate a battalion level organization, all sub-elements of the force in this situation would be expected to occupy positions and assume orientations consistent with a full-sized battalion. In this way, the validity of the situation would be maintained with respect to the expected actions of the forces being employed as targets.

However, it should be recognized that when operations are scaled downward in magnitude, the validity of the test results <u>may</u> be affected adversely. In situations where a smaller sized force is employed to simulate a larger force, and is deployed over the same area as the larger force, target density will be reduced. This could well increase the likelihood that fewer targets will be detected because of the sparse target density. As a result, the capabilities of the system being evaluated may be underestimated. In situations where the target density presented by a smaller force is kept tactically realistic by reducing the area, the search sector employed must be reduced accordingly. Otherwise, much of the time may be spent in searching empty areas. However, reduction of the search sector may affect acquisition in some unknown manner, also compromising the results. Nevertheless, in most cases, the reduction of the search sector and maintenance of realistic target densities is generally preferable.

Scaled down target forces are only one of the ways in which the test officer may be forced to compromise with tactical realities. However, there is a point beyond which compromise cannot be accepted. Unfortunately, this point cannot be precisely defined. Nor can it be said to be obvious to the intelligent and experienced officer. Too often, inappropriate presentations such as side views of stationary targets against plain backgrounds have been employed to simulate attacking enemy armored forces. The test officer must exercise great care in determining his minimum requirements for targets, and should always be guided by considerations of realism rather than by cost or convenience. *An ill-conceived or poorly* *conducted test may well do more damage to our overall defensive posture than no test at all.* Invalid test situations will lead to invalid test conclusions. Invalid conclusions will lead to incorrect decisions concerning procurement, doctrine, and deployment of tested acquisition systems.

However, in determining the degree of realism required, the purposes of the test must be considered. If the intended use of the data is only to make tentative plans or provide guidance for further testing, tests based on marginally realistic situations may produce results which are sufficiently valid for these purposes. On the other hand, if the data from an acquisition field test are to be used for assessing the precise usefulness of a system in combat or for establishing specific combat doctrine, then a much greater degree of realism is necessary.

Summary

The purpose of this chapter was to present information concerning (a) how to control variations in both target and non-target factors to minimize or eliminate extraneous bias in field test results, (b) what types of targets and operational conditions to employ during field tests of target acquisition systems, and (c) means of presenting these targets to observers during testing.

The data bases from which this information was obtained were: a review of the literature on factors influencing the target acquisition process in field situations, and a review of the military literature concerning the Threat on the modern battlefield. These are reported in Chapters 2 and 3, respectively, of this report.

Analysis of the information obtained in the review of the target acquisition and Threat literature revealed that it was only possible in the most general way to describe methodology for developing valid target situations for use in field tests of target acquisition systems designed to be deployed and operated in combat situations. However, it is believed that the guidelines and information presented in this chapter should provide the military test officer with additional background that will enable him to develop more valid target situations for his particular test problem. This should result in better estimates of the operational capabilities of the target acquisition systems tested.

It is realized that the development of realistic and valid target situations alone will not guarantee that valid conclusions will be drawn from a test. Obviously, other principles of good experimental design must also be adhered to. However, with invalid targets, the other principles are of little consequence, as erroneous conclusions are almost certain to result from a test.

LIST OF REFERENCES CITED

Ainsworth, L. and Bishop, H. *The Effects of a 48-Hour Period of Sustained Field Activity on Tank Crew Performance*, HumRRO Technical Report 71-16, Human Resources Research Organization, Alexandria, Virginia, July 1971.

Anstey, R. *Visibility in a Tropical Forest*, Special Report S-3, Earth Sciences Division, US Army Natick Laboratories, Natick, Massachusetts, August 1963.

Anstey, R. *Visibility Measurement in Forested Areas*, Special Report S-4, Earth Sciences Division, US Army Natick Laboratories, Natick, Massachusetts, November 1964.

Armored Cavalry Troop Test, Executive Summary, United States Army, January 1972.

Augustine, N. "Operations Research and the Next War," *Army Research and Development News Magazine*, November-December 1975, 23.

Baldwin, R. *Attempts to Improve Visual Detection Through the Use of Search Patterns and Optical Aids*, HumRRO Technical Report 73-3, Human Resources Research Organization, Alexandria, Virginia, February 1973.

Banks, J., Sternberg, J., Cohen, B., and Debow, C. *Improved Search Techniques with Passive Night Vision Devices*, Technical Research Report 1169, US Army Behavior and Systems Research Laboratory (BESRL), Arlington, Virginia, February 1971.

Banks, J., Sternberg, J., Farrell, J., Dalhamer, W., and Vreuls, D. *Effects of Search Area Size on Target Acquisition with Passive Night Vision Devices*, Technical Research Report 1168, US Army Behavior and Systems Research Laboratory (BESRL), Arlington, Virginia, February 1971.

Banks, J., Sternberg, J., Debow, C., and Dalhamer, W. *Effects of Continuous Military Operations on Selected Military Tasks*, Technical Research Report 1155, US Army Behavior and Systems Research Laboratory, Arlington, Virginia, December 1970.

Bishop, H. *Effects of Information Load, Location, and Mode of Observation on Detecting and Identifying Brief Targets*, HumRRO Technical Report 72-30, Human Resources Research Organization, Alexandria, Virginia, October 1972.

Blackwell, H. and Taylor, J. *Survey of Laboratory Studies of Visual Detection*, paper presented at the NATO Seminar on Detection, Recognition, and Identification of Line-of-Sight Targets, The Hague, Netherlands, 25-29 August 1969.

Brody, H., Corbin, H., and Volkman, J. "Stimulus Relations and Methods of Visual Search," in A. Morris and E. Horne (eds.), *Visual Search Techniques*, Publication 712, National Academy of Science, Washington, D.C., 1960.

Bucklin, B. and Rayner, J. *Development of a Detection Ability Index: I*, ESD IR No. 569 (Draft), Engineering Sciences Division, Feltman Research Laboratory, Picatinny Arsenal, Dover, New Jersey, April 1972.

Burg, A. "Lateral Visual Field as Related to Age and Sex," *Journal of Applied Psychology*, 1968, 52, 10-15.

Canby, S. *The Alliance and Europe, Part IV. Military Doctrine and Technology*, Adelphi Papers, No. 109, The International Institute for Strategic Studies, London, England, Winter 74/75.

Caviness, J. and Maxey, J. *Detection of Human Targets*, HumRRO Technical Report 74-4, Human Resources Research Organization, Alexandria, Virginia, February 1974.

Caviness, J., Maxey, J., and McPherson, J. *Target Detection and Range Estimation*, HumRRO Technical Report 72-34, Human Resources Research Organization, Alexandria, Virginia, November 1972.

Chapanis, A. "How We See: A Summary of Basic Principles," in *A Survey Report on Human Factors in Undersea Warfare*, prepared by the Panel on Psychology and Physiology, Committee on Undersea Warfare, National Research Council, Washington, D.C., 1949, pp 3-60.

Childers, H., Shook, R., Fellin, E., Lerch, P., and Michelsen, P. *Verification Report for SIAF System: Report of Test*, SIAF Report No. 21, The Vertex Corporation, Bethesda, Maryland, September 1971.

Collins, B. and Whittenburg, J. *Defective Color Vision, Filters, Film, and the Detection of Camouflaged Targets: An Annotated Bibliography*, US Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, March 1974.

Conant, J., et al. *Visibility Studies and Some Applications in the Field of Camouflage*, Summary Technical Report, Division 16, National Defense Research Committee, Washington, D.C., 1946.

"Countries and Principal Pacts: The United States and the Soviet Union," in *The Military Balance 1974-1975*, The International Institute for Strategic Studies, London, England, 1974, pp 3-10.

Crawford, W. *The Perception of Moving Objects: I. Ability and Visual Acuity*, FPRC/Memo 150a, Flying Personnel Research Committee, July 1960.

Daignault, D. "The Threat," *Armor*, November-December 1975, 85(6), 37-48.

Dawson, T. "Analysis of Rocket-Assist Aspects of Infantry Antitank Weapons," *Army Research and Development News Magazine*, November-December 1975, 15.

Deese, J. *Changes in Visual Performance After Visual Work*, Johns Hopkins University, Baltimore, Maryland, April 1957.

Dember, W. *The Psychology of Perception*, New York: Holt, Rinehart, and Winston, 1965.

Dictionary of United States Military Terms for Joint Usage. Department of Defense, JCS Publication 1, August 1968.

Dobbins, D., Chu, R., and Kindick, C. *Jungle Vision III: Seasonal Variations in Personnel Detectability in a Semideciduous Tropical Forest*, Research Report No. 8, US Army Tropic Test Center, Panama Canal Zone, January 1967.

Dobbins, D., Chu, R., and Kindick, C. *Jungle Vision VII: Seasonal Variation in Personnel Detectability in a Semideciduous Tropical Forest*, US Army Tropic Test Center, Panama Canal Zone, January 1967.

Dobbins, D. and Gast, M. *Jungle Vision I: Effects of Distance, Horizontal Placement, and Site on Personnel Detection in a Semideciduous Tropical Forest*, US Army Tropic Test Center, Panama Canal Zone, April 1964.

Dobbins, D. and Gast, M. *Jungle Vision II: Effects of Distance, Horizontal Placement, and Site on Personnel Detection in an Evergreen Rain Forest*, US Army Tropic Test Center, Panama Canal Zone, November 1964.

Dobbins, D., Gast, M., and Kindick, C. *Jungle Vision III: Effects of Seasonal Variation on Personnel Detection in an Evergreen Rainforest*, Research Report No. 3, US Army Tropic Test Center, Panama Canal Zone, May 1965.

Dobbins, D., Gast, M., and Kindick, C. *Jungle Vision IV: An Exploratory Study on the Use of Yellow Lenses to Aid Personnel Detection in an Evergreen Rainforest*, Research Report No. 4, US Army Tropic Test Center, Panama Canal Zone, July 1965.

Dobbins, D and Kindick, C. *Jungle Vision V: Evaluation of Three Types of Lenses as Aids to Personnel Detection in a Semideciduous Tropical Forest*, Research Report No. 5, US Army Tropic Test Center, Panama Canal Zone, December 1965.

Dobbins, D. and Kindick, C. *Jungle Vision VI: A Comparison Between the Detectability of Human Targets and Standard Visibility Objects in an Evergreen Rainforest*, Research Report No. 6, US Army Tropic Test Center, Panama Canal Zone, February 1966.

Drucker, E., Cannon, L., and Ware, J. *The Effects of Sleep Deprivation on Performance Over a 48-Hour Period*, HumRRO Technical Report 69-8, Human Resources Research Organization, Alexandria, Virginia, May 1969.

Drummond, R. and Lackey, E. *Visibility in Some Forest Stands of the United States*, Technical Report EP-36, Quartermaster Research and Development Command, Natick, Massachusetts, May 1956.

Dubuisson, A. and Kindick, C. *Jungle Vision VIII: Visual Detection of Moving Targets in a Semitropic Forest*, Interim Report, US Army Tropic Test Center, Panama Canal Zone, October 1971.

Dudek, R., George, C., and Ayoub, M. "Performance Recovery and Man-Machine Effectiveness," in US Army Human Factors Research and Development, *Proceedings of the 15th Annual Conference*, November 1969.

Duke, M., Findikyan, N., Anderson, J., and Sells, S. *Stress Reviews: Thermal Stress-Heat*, Technical Report No. 11, Institute of Behavioral Research, Texas Christian University, Fort Worth, May 1967.

Duke, M., Findikyan, N., and Sells, S. *Stress Reviews: Thermal Stress-Cold*, Technical Report No. 8, Institute of Behavioral Research, Texas Christian University, Fort Worth, May 1967.

Eckles, A., Garry, T., Mullen, W., and Aschenbrenner, H. *HELAST II*, Technical Memorandum 12-73, US Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, 1973.

Erickson, J. "Soviet Military Capabilities in Europe," *Journal of the Royal United Services Institute for Reference Studies*, Great Britain, March 1975.

Farrar-Hockley, A. "II. The October War," in E. Monroe and A. Farrar-Hockley, *The Arab-Israeli War, October 1973, Background and Events*, Adelphi Papers, No. 111, The International Institute for Strategic Studies, London, England, Winter 74/75, pp 14-31.

Farrell, J., Banks, J., and Sternberg, J. *Search Effectiveness With the Starlight Scope and 7x50 Binoculars*, Technical Research Report 1164, Behavior and Systems Research Laboratory, Office of the Chief of Research and Development, Arlington, Virginia, June 1970.

FM 17-50. *Attack Helicopter Operations* (Draft), Department of the Army, US Army Armor School, Fort Knox, Kentucky, October 1975.

Fox, W. *Visual Discrimination as a Function of Stimulus Size, Shape, and Edge Gradient*, WADC Technical Note 57-132, Wright Air Development Command, Wright-Patterson AFB, Ohio, August 1957.

Gee, D. and Humphreys, A. *User Review of Camouflage for the Individual Soldier in the Field*, US Army Engineer Research and Development Laboratories, October 1965.

Geldard, F. *The Human Senses*, New York: John Wiley, 1952.

Gordon, D. and Lee, G. *Model Simulator Studies - Visibility of Military Targets as Related to Illuminant Position*, University of Michigan, Ann Arbor, March 1959.

Gottsdanker, R. "The Relation Between the Nature of the Search Situation and the Effectiveness of Alternative Strategies of Sectors," in A. Morris and E. Horne (eds.), *Visual Search Techniques*, Publication 712, National Academy of Science, Washington, D.C., 1960.

Graham, C. "Visual Space Perception," in C. Graham (ed.), *Vision and Visual Perception*, New York: John Wiley, 1965.

Guttman, H. and Webster, R. "Determining the Detectability Range of Camouflaged Targets," *Human Factors*, 1972, 14, 217-225.

Hein, K. "Old Lessons Learned," *Armor*, September-October 1975, 85(5), 30-36.

Heisenberg, W. *The Alliance and Europe: Part I: Crisis Stability in Europe and Threat Nuclear Weapons*, Adelphi Papers, No. 96, The International Institute for Strategic Studies, London, England,

Helson, H. and Fehrer, E. "The Role of Form in Perception," *American Journal of Psychology*, 1932, 44, 79-102.

Hoffman, H. *The Maximum Detection Range and Discovery of Land Vehicles*, DFL 0475, Deutsche Forschungsanstalt fur Luft - und Raumfahrt, Institut fur Flugfuhrung, April 1968.

Humphreys, A. and Gee, D. "Experimental Design for User Review of Camouflage for the Individual Combat Soldier," in *Army Human Factors Engineering Conference*, Eighth Annual, Army Research Office, Office of Chief of Research and Development, Department of the Army, November 1962.

James, J. and James, W. Unpublished study reported in R. Anstey, *Visibility Measurement in Forested Areas*, Special Report S-4, Earth Sciences Division, US Army Natick Laboratories, Natick, Massachusetts, November 1964.

Johnston, D. *Search Performance as a Function of Peripheral Acuity*, Research Report D6-571000, Boeing Company, June 1975.

Jones, D., Freitag, M., and Collyer, S. *Air-to-Ground Target Acquisition Source Book: A Review of the Literature*, Martin-Marietta Corporation, Orlando, Florida, 1974.

Kobrick, J. "Environmental Factors Affecting Visual Perception," in *US Army Human Factors Research and Development Conference Report*, Sixteenth Annual Conference, Fort Bliss, Texas, October 1970, pp 165-178.

Krendel, E. and Wodinsky, J. "Visual Search in Unstructured Fields," in A. Morris and E. Horne (eds.), *Visual Search Techniques*, Publication 712, National Academy of Science, Washington, D.C., 1960.

Kristofferson, A. *Visual Detection as Influenced by Target Form*, paper presented at Target Acquisition Symposium, Naval Training Device Center, Orlando, Florida, November 1972.

Lindsley, D., et al. *Radar Operator "Fatigue": The Effects of Length and Repetition of Operating Periods on Efficiency of Performance*, Report No. SRO 3334, Office of Scientific Research and Development, 1944.

Lit, A. "Visual Acuity," in P. Farnsworth (ed.), *Annual Review of Psychology*, 1968, 19, 27-54.

Lovasz, S. "Soviet Motorized Rifle Company," *Infantry*, November-December 1975, 65(6), 30-35.

Martinek, H., Tanck, R., and Mellinger, J. *Field Evaluation of ANST-Armoured Patrol*, Research Memorandum 59-12, Personnel Research Branch, Adjutant General's Office, November 1959.

Maxey, J. and Caviness, J. *Target Detection in the Field*, HumRRO Professional Paper 11-72, Human Resources Research Organization, Alexandria, Virginia, May 1972.

Maxey, J., Powers, T., Jacobs, T., and Magner, G. *Identification of the Potential Characteristics, Aptitudes, and Acquired Skills Involved in Human Detection of Mines*, HumRRO Technical Report 73-18, Human Resources Research Organization, Alexandria, Virginia, August 1973.

McGrath, J., Harabedian, A., and Buckner, D. *Review and Critique of the Literature on Vigilance Performance*, Technical Report 206-1, Human Factors Research, Inc., Goleta, California, December 1959.

Nichols, T. and Powers, T. *Moonlight and Night Visibility*, HumRRO Research Memorandum, Human Resources Research Organization, Alexandria, Virginia, January 1964.

Night Operations and the Employment of Night Vision Devices (U), US Army Combat Developments Command, November 1964 (SECRET).

Pollack, I. and Knaff, P. "Maintenance of Alertness by a Land Auditory Signal," *Journal of the Acoustical Society of America*, 1958, 30, 1013-1016.

Pretty, R. (ed.). *Jane's Weapon Systems,* (7th ed.), New York: Franklin Watts, Inc., 1975.

Pretty, R. and Archer, D. (eds.). *Jane's Weapon Systems 1970-1971* (2nd ed.), New York: McGraw-Hill, 1970.

"Principles of Night Combat," *Japanese Night Combat, Part 1.* Headquarters, US Army Forces, Far East, Eighth US Army Military Section, Japanese Research Division, undated.

Richardson, F. *Target Acquisition Performance by Ground Observers - A Physical Interpretation,* Technical Report, Army Combat Developments Command, Fort Ord, California, July 1968.

Riggs, L. "Light as a Stimulus for Vision," in C. Graham (ed.), *Vision and Visual Perception,* New York: John Wiley, 1965.

Savkin, V. *The Basic Principles of Operational Art and Tactics (A Soviet View),* Moscow, 1972.

Skinner, D. and Jenkins, S. *A Rationale for the Design of a Camouflage Uniform,* MRL Report 598, Materials Research Laboratories, Maribyrnong, Australia, 1974 (Restricted).

Smith, S. *Time Required for Target Detection in Complex Abstract Visual Displays,* Memorandum 2900-235-R, University of Michigan, Ann Arbor, April 1961.

Smith, G., Skinner, D., and Jenkins, S. *A Preliminary Comparison of the Detectability of Certain Camouflage Uniforms,* DSL Report 593, Defence Standards Laboratories, Maribyrnong, Australia, 1973 (Restricted).

Snyder, H. "Dynamic Visual Search Patterns," in *Visual Search,* Minutes of Symposium Conducted at the Spring Meeting of Committee on Vision (1970), National Research Council, Washington, D.C., 1973.

Sternberg, J. and Banks, J. *Search Effectiveness With Passive Night Vision Devices,* Technical Research Report 1163, Behavior and Systems Research Labcratory, Arlington, Virginia, June 1970.

Stollmack, S. and Brown, P. "Detection Time Analysis," in D. Howland and G. Clark (eds.), *The Tank Weapon System;* Report RF-573, Ohio State University, Systems Research Group, Columbus, 1966.

Synder, H. and Greening, C. *The Effect of Direction and Velocity of Relative Motion Upon Dynamic Visual Acuity,* C5-447/3111, Autonetics Division, North American Aviation, Inc., Anaheim, California, January 1965.

Tammien, D. "How to Defend Outnumbered and Win," *Armor,* November-December 1975, 85(6), 39-45.

Taylor, J. *Moonlight I: Identification of Stationary Human Targets*, HumRRO Research Memorandum 21, Human Resources Research Organization, Alexandria, Virginia, December 1960.

TC 7-24. *Antiarmor Tactics and Techniques*, Department of the Army, US Army Infantry School, Fort Benning, Georgia, 30 September 1975.

TC 17-17. *Gunnery Training for Attack Helicopters* (Draft), Department of the Army, US Army Armor School, Fort Knox, Kentucky, 1 August 1975.

"The Theatre Balance Between NATO and the Warsaw Pact," in *The Military Balance 1974-1975*, Institute Staff, The International Institute for Strategic Studies, London, England, 1974, pp 95-102.

Thomas, F. and Caro, P. *Training Research on Low Altitude Visual Aerial Observation: A Description of Five Field Experiments*, HumRRO Research Memorandum, Human Resources Research Organization, Alexandria, Virginia, July 1962.

Tiffen, J. and McCormick, E. *Industrial Psychology*, Englewood Cliffs, New Jersey: Prentice-Hall, 1965.

TRADOC Bulletin 1 (U). *Range and Lethality of U.S. and Soviet Anti-Armor Weapons*, Department of the Army, US Army Training and Doctrine Command, Fort Monroe, Virginia, 30 September 1975.

TRADOC Bulletin 2 (U). *Soviet ATGMs: Capabilities and Countermeasures*, Department of the Army, US Army Training and Doctrine Command, Fort Monroe, Virginia, April 1975.

TRADOC Bulletin 8. *Modern Weapons on the Modern Battlefield*, Department of the Army, US Army Training and Doctrine Command, Fort Monroe, Virginia.

Turviville, G. "A Soviet View of Heliborne Assault Operations," *Military Review*, October 1975, 55(10), 3-15.

User Review of Individual Camouflage. Project No. 2989, US Army Infantry Board, Fort Benning, Georgia, March 1963.

Van Meeteren, A. and Zonneveld, F. *Object Recognition in Aided and Unaided Night Vision*, Report IZF 1971-7, Institute for Perception RVO/TNO, Sonesterberg, The Netherlands, 1971.

Von Fieandt, K. *The World of Perception*, Homewood, Illinois: Dorsey Press, 1966.

Wallace, S., Hexter, P., and Hecht, S. *Color Vision and Its Relation to the Detection of Camouflage*, Army Research Bulletin 43-6, October 1943.

Walton, L. *Service Test of Night Vision Sight, Crew-Served Weapons, AN/TVS-5 (Second Generation)*, AIB 73-561, Partial Report, US Army Infantry Board, Fort Benning, Georgia, February 1973.

Whitehurst, H. *Effect of Camouflage Paint Pattern on the Surface-to-Surface Detection of Vehicles*, NWC TP 5772, Naval Weapons Center, China Lake, California, June 1975.

Whitehurst, H. *The Effects of Pattern and Color on the Visual Detection of Camouflaged Vehicles*, NWC TP 5746, Naval Weapons Center, China Lake, California, March 1975.

Woodworth, R. and Schlosberg, H. *Experimental Psychology*, New York: Holt and Company, 1954.

Wulfeck, J., et al. *Vision in Military Aviation*, WADC Technical Report 58-399, Wright Air Development Command, US Air Force, Wright-Patterson AFB, Ohio, November 1958.